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GLOSSARY OF TERMS

Alluvium - Sediments (e.g. clay, mud, silt, sand and gravel) deposited by erosional processes, usually by streams

Aquifer- Permeable layers of underground rock, or sand that hold or transmit groundwater below the water table that will yield water

Aquitard - A formation which contains groundwater but cannot transmit it rapidly enough to furnish a significant supply to a well or spring

Argillaceous - Rocks composed of clay minerals, or having notable proportion of clay in their composition such as shale and slate.

Artesian bore - A bore drilled into a confined aquifer with enough hydraulic pressure for the water to flow to the surface without pumping (also called a flowing well)

Cainozoic - The period of geological time extending from approximately 65 million years ago up to the present

Calcareous – Limy or chalky rock or soil containing a high proportion of calcium carbonate

Carbonaceous - Sediment or rock containing very small grains of carbon distributed evenly throughout the rock, giving it a black colour.

Cation – A positively charged ion in solution

Confined aquifer - An aquifer bounded above and below by impermeable beds or by beds of distinctly lower permeability than that of the aquifer itself

Conglomerate - A sedimentary rock composed of gravel, cobbles and boulders mixed in with sand or mud.

Cretaceous - The period of geological time extending 145 – 65 million years ago.

Electrical conductivity - a measure of the ionic activity of a solution in term of its capacity to transmit current

Fault – A planar rock fracture which shows evidence of relative movement on either side of the fault surface

Great Artesian Basin – An extensive sequences of laterally connected sedimentary rock aquifers extending across much of inland Queensland and certain areas of inland NSW, South Australia and the Northern Territory that encompass the include the geological entities of the Surat Basin, Eromanga Basin, Carpentaria Basin and part of the upper Bowen Basin

Groundwater – Water beneath the surface of the earth which saturates the pores and fractures within sediment and rock formations.

Jurassic - The period of geological time extending from 213 to 145 million years ago

Labile – Readily undergoing change or breakdown.

Mudstone - A sedimentary rock composed of clay-size particles but which lacks the stratified structure characteristic of a shale.

Perennial stream – A stream with flow that is permanent and continuous

Potentiometric surface - The water level surface that can be defined from the mapping of water level elevations in bores tapping into a confined aquifer

Quaternary – The period of geologic time extending from 1.8 million years ago to the current time

Sandstone – A sedimentary rock composed mainly of sand-size mineral or rock grains.

Sedimentary rock – A rock that has generally formed from initially unconsolidated sediment such as clay, silt, sand or gravel, however it should be noted that certain types of sedimentary rock form from chemical processes such as certain types of limestone.

Shale - A fine-grained sedimentary rock, formed by the compaction of clay, silt, or mud.
Siltstone – A sedimentary rock composed of silt-sized particles

Spring – The point where groundwater flows out of the ground, and is thus where the aquifer surface meets the ground surface.

Spudded – Commenced in (e.g. a bore spudded in the Precipice Sandstone will have commenced drilling at the surface in an outcrop of Precipice Sandstone)

Stratigraphic – Pertaining to the study of the subdivision, composition, age and correlation of sedimentary rocks

Stream gauging station – A site on a stream where the level and rate of flow in a stream can be measured. Such stations may be equipped to continually monitor stream level and flow or may be sites where spot measurements of stream level and flow area made.

Subartesian bore - A bore drilled into an aquifer that does not have enough hydraulic pressure for the water to flow to the surface without pumping

Sublabile – Minerals that are not fully subject to ready change or breakdown.

Surat Basin – A geological entity which consists of a series of vertically layered formations and forms part of the Great Artesian Basin of Australia. The Surat Basin extends across an area of 27,000 km^2 mainly in Queensland although the southern third of the basin occupies a large part of northern New South Wales. The rocks in the Surat Basin largely comprise Jurassic through to Cretaceous age sediments.

Syncline – A fold in rocks in which the strata dip inward from both sides (limbs) toward the axis.

Total dissolved solids (TDS) - A measure of the total amount of dissolved mater in water, and indication of the total salinity of water.

Transmissivity - The rate at which groundwater can flow through an aquifer section of unit width under a unit hydraulic gradient. It is the average permeability of a section of the entire aquifer at a given location multiplied by the thickness of the formation.

Unconfined aquifer - An aquifer containing water that is not under pressure. The water level measured in a bore drilled into an unconfined aquifer is the same as the water table outside the bore.

15. GROUNDWATER

This chapter addresses Section 3.4.2 of the ToR. It describes the relevant State and Federal regulatory frameworks, the existing groundwater resources within the Project area, the potential impacts of the Project in relation to groundwater resources, and potential mitigation measures to manage impacts.

15.1. Description of environmental values

15.1.1. Regulatory framework

Key elements of the regulatory framework for groundwater management in the Project area are:

- *Water Act 2000;*
- *Water Regulation 2002;*
- *Water Resource (Great Artesian Basin) Plan 2006;* and
- Great Artesian Basin Resource Operations Plan (NRW, 2007).

15.1.1.1. Water Act 2000

The *Water Act 2000* (Qld) provides a framework for the sustainable management of water and related resources. The Act regulates the taking, use and allocation of water through (among other things) water resource plans (WRPs) and resource operations plans (ROPs).

The main elements of the *Water Act 2000* relevant to this Project are:

- WRPs and ROPs can be produced to allow regulation of groundwater;
- a system of licensing of water bore drillers prohibits the construction of bores by unlicensed drillers; and
- requirements for the holders of a water bore driller's licence to keep prescribed information for all water bores constructed greater than 6 m deep.

15.1.1.2. Water Regulation 2002

The *Water Regulation 2002* is subordinate legislation to the *Water Act 2000*. The main elements of the *Water Regulation 2002* relevant to the Project are:

- delineation of declared subartesian areas (including the Great Artesian Basin (GAB) subartesian area);
- types of groundwater uses that do not require licences within declared subartesian areas;
- licensing requirements of water bore drillers (including specified classes of drillers licences to operate in artesian areas);
- requirements that water bores be constructed and decommissioned in accordance with the document *Minimum Construction Requirements for Water Bores in Australia* (Land and Water Biodiversity Committee, 2003); and
- specification of the information water bores drillers must record.

The GAB subartesian area was declared under the *Water Regulation 2002*. For all declared subartesian areas a water licence is required to take or interfere with subartesian water and a development permit is required to construct or install works that take subartesian water other than for domestic or stock purposes from subartesian aquifers not connected to artesian aquifers.

15.1.1.3. Water Resource (Great Artesian Basin) Plan 2006

The purpose of the *Water Resource (Great Artesian Basin (GAB)) Plan 2006 (*the GAB WRP*)* is to define the availability of water in the plan area; to provide a framework for sustainably managing water and the taking of water; and to identify priorities and mechanisms for dealing with future water requirements. The plan provides 25 Management Areas and Management Units within the overall plan area, for which volumes of additional unallocated water have been assigned.

The Management Areas potentially relevant to the Project include Surat North, Surat East and Eastern Downs. The locations of these Management Areas are shown in Schedule 2 of the GAB WRP.

The plan applies to the following water from the plan area:

- artesian water;
- subartesian water connected to artesian water;
- water in springs connected to:
  - artesian water; or
  - subartesian water connected to artesian water.

Under Section 8 of the GAB WRP, water is to be allocated and managed in a way that seeks to achieve a balance in the following outcomes:

a) to protect the flow of water to springs and baseflow to watercourses that support significant cultural and environmental values;

b) to provide for the continued use of all water entitlements and other authorisations to take or interfere with water;

c) to reserve water in storage in aquifers for future generations;

d) to ensure a reliable supply of water from the plan area; and

e) to make water available for new users.

Unallocated water is divided into a General reserve and a State reserve. Under the GAB WRP unallocated water may be granted from the State reserve only for the following purposes:

- a project of State significance;
- a project of regional significance; and
- for water granted to a local government—town water supply purposes.

Schedule 5 of the GAB WRP provides summary data for the unallocated water within the General reserve for each Management Areas.

15.1.1.4. GAB Resource Operations Plan 2007

The GAB ROP (NRW, 2007) applies to the same water as does the water resource plan.

The ROP provides the details that will allow for:

- release of unallocated water from the GAB;
- protection of flow of water to springs and baseflow to watercourses;
- protection of existing entitlements;
- provision of volumetric licences to local governments for existing town water supply;
- provision of rules for relocating licences;
- provision of water sharing and seasonal water assignment rules;
- monitoring of flow to springs and baseflow to watercourses;
- dealings with existing and new water licence applications and amendments to existing licences; and
- amendments that can be made to the ROP.

Currently a moratorium on the development of additional groundwater supplies from the GAB is in place and registrations of interest have been sought from the public regarding applications to access unallocated water specified in the plan. Although the ROP was gazetted in February 2007, at the time of preparation of this document no unallocated water had been allocated from either the General or State reserve.

15.1.2. Methodology

The following assessment of the groundwater resources at the dam site and pipeline is based on the review and interpretation of the following sources of data:

- groundwater data from DERM groundwater database – aquifer details, bore locations, construction, groundwater level, groundwater quality, stratigraphic logs, bore yields;
- available data on groundwater entitlements stored by DERM on its Water Entitlements System, at 26 July 2010;
- climate data from the BOM;
- GIS layers (e.g. surface geology, spring locations, land use, water storage);
- Digital Elevation Model for the study area;
- Springs of Queensland - Distribution and Assessment (Version 5.0);
- Chenoweth flora report (2008);
- GAB ROP (NRW, 2007); and

- review of key relevant geological and hydrogeological reports for the area, including *The impact of Nathan Dam on Boggomosses and regional hydrology* (DNR, 1996); *GAB Resources Study* (Cox and Barron (Eds), 1998).

15.1.3. Dam and surrounds

The dam site is located on the Dawson River approximately 11 km downstream of Glebe Weir and 8 km upstream of Nathan Gorge (Figure 1-2). Taroom is the closest town upstream of the dam (75 km) and Theodore is the closest town located on the river downstream of the dam (85 km).

15.1.3.1. Geology

The geology of the dam and surrounds is discussed in Chapter 6. A summary of this information is provided below. The surficial geology of the dam and surrounds is shown in Figure 6-2.

The Nathan Dam catchment represents the southern part of the Fitzroy Basin, central, south eastern Queensland. The dam site and water storage area is directly underlain by Quaternary age alluvium associated with the Dawson River and its tributaries and the consolidated sedimentary rocks of the Surat Basin, an extensive unit within the GAB. The Surat Basin is a large Early Jurassic to Early Cretaceous basin that contains sediments that are largely flat-lying and relatively uniform. Consolidated Triassic aged sedimentary rocks of the Bowen Basin underlie the Surat Basin at depth, outcropping to the east of the dam site. Beneath the Bowen Basin rocks lie older Permian age volcanic rocks of the Connors – Auburn Arch. These older rocks effectively form basement to the area.

The Surat Basin sequence at the dam site consists of the lower Jurassic age Precipice Sandstone which is the basal unit of the basin. The upper section of the Precipice Sandstone consists of fine grained silty sandstones which include some shale and carbonaceous shale horizons while the lower section consists of cleaner and more permeable medium and coarse grained quartzose sandstones (DNR, 1996). The sandstone unit has an overall gentle dip to the south-west towards the Mimosa Syncline, a major regional fold structure. A cross section of the main aquifers within the Surat Basin is shown in Figure 15-1.

To the west of the dam wall the Precipice Sandstone is overlain by the lower Jurassic age Evergreen Formation which is overlain in turn by the lower to middle Jurassic age Hutton Sandstone and the middle Jurassic age Injune Creek Group, all of which have the same broad, gentle, general dip direction to the south-west.

DNR (1996) have described the Evergreen Formation as consisting predominantly of shales and mudstones with argillaceous silty sandstones, particularly near its base. The Hutton Sandstone was described as a generally thick bedded, fine to medium grained argillaceous sandstone.

The uppermost unit of the Surat Basin, the Injune Creek Group, consists of a series of formations that are not differentiated in the published surface geological mapping but which can be differentiated in subsurface. The relevant formations of the Injune Creek Group in the area around the water storage are the Birkhead Formation, the Eurombah Formation and the Walloon Coal Measures.

The Birkhead Formation is a sedimentary formation of freshwater origin and consists mainly of shales and a basal sequence of low permeability clay bound sandstones (DNR, 1996). Green (1997) described the Eurombah Formation as thickly cross-bedded labile to sublabile sandstones and interbedded siltstones and mudstones. The Walloon Coal Measures generally consist of claystone, shale, siltstone, lithic and sublithic to feldspathic arenites and coal seams.

Notwithstanding the presence of obvious linear features in the traces of major stream drainage, the available published surface mapping coverage indicate the presence of few if any mapped faults. It is likely that there will be a greater number of faults actually present in the region that hosts the dam and surrounds than that indicated in the published regional surface geological mapping. Faults can be conduits allowing preferential vertical migration of groundwater. As such, it is likely that the location of many of the artesian springs in the area is influenced by the presence of faults and fracture systems associated with faults.

The Dawson River has incised into the rocks of the Surat Basin and Quaternary age alluvial sediments have been deposited by the river and adjacent streams such as Boggomoss Creek. Paton (2008) has indicated that drilling and seismic profiling indicated that the dam site is underlain by up to 15 m of clay and clayey sand alluvium associated with the Dawson River.

15.1.3.2. Hydrogeology

The key aquifer systems in the study area can be broadly grouped into:

- sedimentary aquifers of the Bowen Basin and underlying minor fractured rock aquifers of the volcanic rocks of the Connors – Auburn Arch;
- significant consolidated sandstone aquifers (Precipice Sandstone and Hutton Sandstone) of the Surat Basin, interlayered with generally poorly permeable consolidated shale, siltstone, mudstone and fine grained sandstone aquitards (Evergreen Formation and Injune Creek Group – Birkhead Formation, Eurombah Formation, Walloon Coal Measures); and
- minor to significant unconsolidated sedimentary aquifers associated with the alluvium of the Dawson River and its major tributaries.

The Permian age volcanic units of the Connors – Auburn Arch such as the Camboon Andesite form poorly permeable fractured and weathered rock aquifers. These rocks effectively constitute a hydrological basement beneath the Bowen Basin rocks. The upper sequence of the Bowen Basin formations in the vicinity of the water storage include; the Rewan Formation and Baralaba Coal Measures. These units substantially represent fine grained and poorly permeable aquitards that effectively form a hydrologic basement beneath the Surat Basin rocks. The Surat Basin and Bowen Basin and are considered structurally separate sedimentary depositional centres. They are however stratigraphically and hydraulically interconnected (DME, 1997). Due to the fact that the impacts of the dam will be local however, it has been assumed that there will be no impact on the older Bowen Basin system.

The key aquifers of the Surat Basin are formed by the sandstones of the Precipice Sandstone and the Hutton Sandstone. The Precipice Sandstone is a major and often highly productive, consolidated sedimentary rock aquifer that has both intergranular porosity and permeability, and secondary fracture/joint related porosity and permeability. Larger individual groundwater supplies drawn from the Precipice Sandstone are often associated with zones of increased jointing or fracturing of the sandstone. The Precipice Sandstone is a confined aquifer where it is overlain by the Evergreen Formation. Where the Precipice Sandstone outcrops it can have characteristics of both an unconfined aquifer and a confined/semi-confined aquifer depending on the extent of lower permeability silt and clay layers present within the formation.

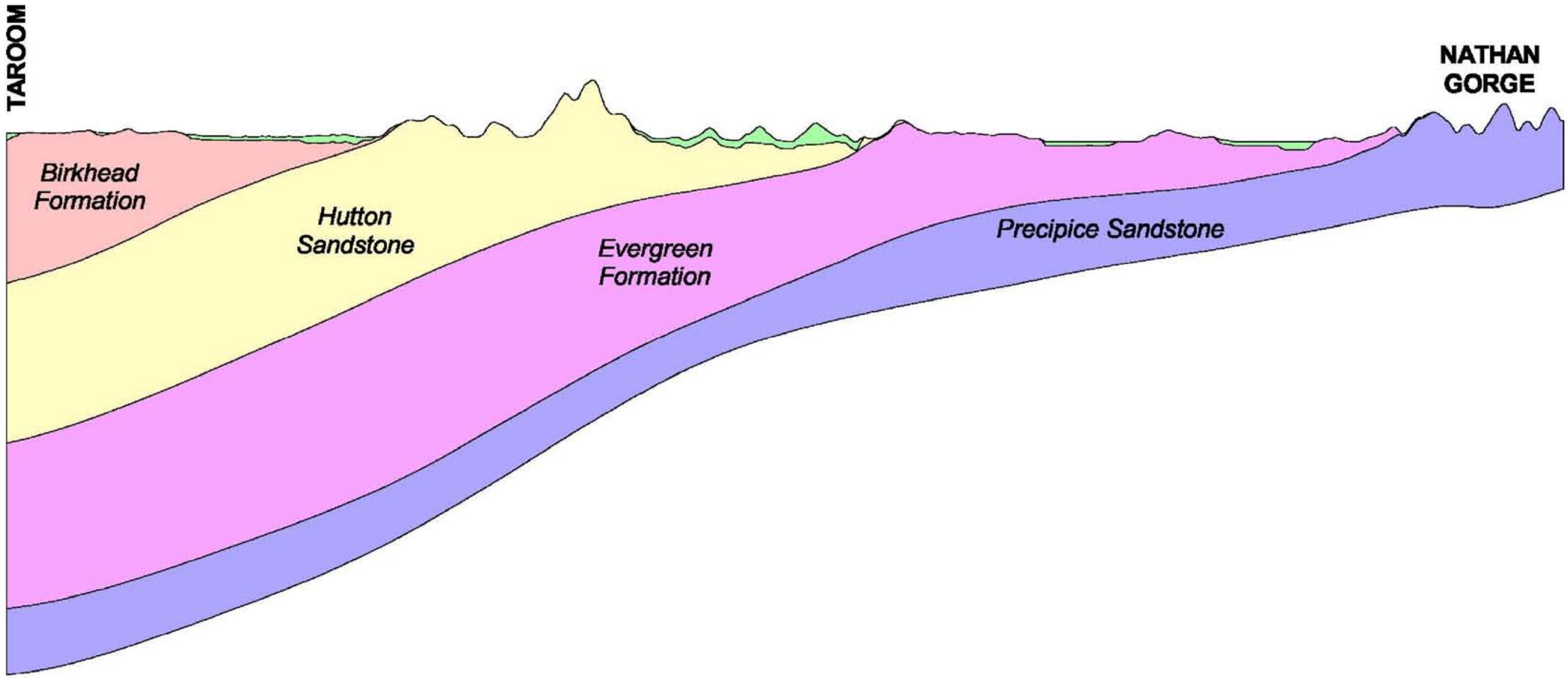
The Evergreen Formation is generally considered to be a relatively low permeability aquitard that largely acts as a confining bed where it overlies the Precipice Sandstone. Geological logs of some groundwater bores that tap the Evergreen Formation in the Boggomoss Creek area have indicated that water supplies occur in association with fractured shales with these most probably being fault-related.

The Hutton Sandstone is a significant, although only moderately productive, consolidated sedimentary rock aquifer that has both intergranular porosity, as well as secondary fracture porosity. The Hutton Sandstone is a confined aquifer where it is overlain by the Injune Creek Group. Similar to the Precipice Sandstone, where the Hutton Sandstone outcrops it can have characteristics of both an unconfined aquifer and a confined/semi-confined aquifer depending on the extent of lower permeability silty and/or clayey layers. Forbes (1968) suggested that the Hutton Sandstone was not a reliable supplier of potable water and that within it, the distribution of water supplies was erratic and it is commonly brackish.

The Injune Creek Group hosts a series of individual formations the most significant of which in the study area are the Birkhead Formation, the Eurombah Formation and the Walloon Coal Measures. In general, these formations form poorly productive consolidated sedimentary rock aquifers that have largely intergranular porosity and permeability and joint related porosity and permeability in associated thin coal seams. These units substantially form aquitards where they overlie the Hutton Sandstone.

At the dam and surrounds, the Precipice Sandstone has an average thickness of 50 to 100 m, with the greatest thicknesses (>100 m) to the south of Taroom and around Nathan Gorge. The overlying Evergreen Formation has an average thickness of 200 m, with the thickest sediments (> 300 m) to the south-east of Taroom. The Hutton Sandstone has an average thickness in the order of 100 to 200 m, while the Injune Creek Group varies in thickness up to approximately 300 m to the south of Taroom. The interpreted extent and thickness of the four major formations are shown in Figure 15A-1 to Figure 15A-4 in Appendix 15A.

Forbes (1968) suggested that the alluvium of the larger streams within the Project area generally yield good supplies of groundwater at shallow depth, however the alluvium of the Dawson River varies from a poorly productive to significantly productive unconsolidated Alluvial aquifer system depending on the clay content and depth of aquifer saturation at any particular location.



LEGEND

- Alluvium
- Birkhead Formation
- Hutton Sandstone
- Evergreen Formation
- Precipice Sandstone

Projection: GDA94 Zone 56

Figure 15-1

NOT TO SCALE (at A4)

SKM SunWater Making Water Work

NATHAN DAM AND PIPELINES EIS

Cross section through the Project area - Nathan Gorge to Taroom

15.1.3.3. Aquifer properties

Hydraulic conductivity values in the confined aquifers of the GAB range from 0.1 to 10 m/day (Cox and Barron (Eds), 1998). Reported ranges of aquifer transmissivity for bores screened in the relevant Surat Basin aquifers include (P. Evans, pers. comm.):

- Precipice Sandstone 12 – 6,954 m^2/day (sample of 21 bores); and
- Hutton Sandstone 3 – 223 m^2/day (sample of 19 bores)

15.1.3.4. Proximity and value of groundwater facilities

A search of the DERM groundwater database was undertaken for the Project area using the following search coordinates (GDA 94):

- top left: Latitude 149.644, Longitude -25.286; and
- bottom right: Latitude 150.552, Longitude -25.783.

A total of 204 registered groundwater bores were identified in the search. A summary of the artesian/subartesian status of bores is provided in Table 15-1. More detailed information on all registered bores within the Project area is provided in Appendix 15-B.

The majority of the bores in the Project area are screened in the Precipice Sandstone (50%) whilst an additional 25% screen the Hutton Sandstone (Table 15-1). Within the Precipice Sandstone, approximately half of the bores are artesian, of which only one has reported to have ceased flow. By contrast, within the Hutton Sandstone over 95% of the bores are reported to be subartesian.

Table 15-1 Summary of the artesian / subartesian status of bores

Formation	Total number of bores	Total number of subartesian bores	Proportion of subartesian bores	Total number of artesian bores	Proportion of artesian bores	Total number of artesian bores that are recorded as ceased flowing	Proportion of artesian bores that are recorded as ceased flowing
Alluvium	3	3	100%	0	0%	n/a	n/a
Birkhead Formation	8	4	50%	4	50%	1	25%
Eurombah Formation	6	5	83%	1	17%	1	100%
Hutton Sandstone	50	48	96%	2	4%	0	0%
Evergreen Formation	8	8	100%	0	0%	n/a	n/a
Precipice Sandstone	102	49	48%	53	52%	1	2%
Not Defined	27	20	74%	7	26%	0	0%
Subtotal	**204**	**137**	**67%**	**67**	**33%**	**3**	**4%**

A summary of preliminary hydrogeological data from geotechnical investigations at the dam site is provided in Table 15-2. The collated data indicates that the potentiometric surface in the Precipice Sandstone ranges from 167 m AHD to 173.8 m AHD. Bores constructed to screen the Precipice Sandstone in the floor of the valley at the dam site where the natural surface elevation is in the order of 160 m AHD, are artesian. Maximum artesian flows from these geotechnical investigation bores have been 10 L/s (PB, 2008).

Table 15-2 Summary of preliminary hydrogeological data at site of Nathan Dam (modified after PB, 2008)

Dam investigation borehole identifier	Surface elevation of hole (m AHD)	Total depth of hole (m)	Date of water level measurement (m)	Maximum water level reached in borehole (m AHD)	Maximum recorded pressure (kPa)	Maximum discharge from borehole (L/m)	Maximum discharge from borehole (L/s)	Total salinity (ppm)	Approximate electrical conductivity (µS/cm)	pH	Groundwater temperature (degrees C)
DD7	183	n/a	7/10/2008	169.1	n/a	n/a - subartesian	n/a - subartesian	n/a	n/a	n/a	n/a
DD8	190.3	58.00	18/10/2008	173.8	n/a	n/a - subartesian	n/a - subartesian	n/a	n/a	n/a	n/a
DD10	174	n/a	18/09/2008	167	n/a	n/a - subartesian	n/a - subartesian	n/a	n/a	n/a	n/a
DD11	n/a	37.50	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DD12	166	35.00	26/09/2008	n/a	n/a	85	1.42	223.8	373	6.93	n/a
DD13	169	40.00	8/10/2008	170.1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DD14	161	38.00	n/a	n/a	50	480	8.00	n/a	n/a	n/a	n/a
DD15	158	32.00	n/a	n/a	55	185	3.08	n/a	n/a	n/a	n/a
DD16	159	26.00	n/a	n/a	n/a	350	5.83	n/a	n/a	n/a	n/a
DD17	159.5	20.00	n/a	n/a	n/a	20	0.33	n/a	n/a	n/a	n/a
DD18	160.5	40.00	n/a	n/a	n/a	600	10.00	206.2	344	6.7	n/a
DD19	161	30.00	n/a	n/a	45	60	1.00	83.7	140	6.2	18.2
DD21	178	50.00	20/09/2008	168.3	n/a	n/a - subartesian	n/a - subartesian	n/a	n/a	n/a	n/a
DD22	194.4	60.00	3/07/2008	168.8	n/a	n/a - subartesian	n/a - subartesian	n/a	n/a	n/a	n/a
DD23	197.3	80.00	7/08/2008	173	n/a	n/a - subartesian	n/a - subartesian	n/a	n/a	n/a	n/a

15.1.3.5. *Groundwater levels*

The most recent available groundwater level measurements for all of the DERM registered groundwater bores are provided in Appendix 15-B. The positive values in the depth to groundwater level table indicate an artesian groundwater level above ground surface.

Depth to groundwater varies significantly across the study area. The highest artesian water level is 34.2 m above ground level recorded on 5th March 1976 for bore 17070 screening the Precipice Sandstone. This bore is located 17 km north-west of Taroom. The deepest subartesian water level indicated in the Project area is 73.1 m below ground level recorded on 7th June 1960 for bore 10475. This bore is located along Glebe Weir road, screening the Hutton Sandstone.

There are limited available temporal records of groundwater levels for water bores in the area of interest. Appendix 15-C shows the bores with two or more individual groundwater level observations. A series of nine groundwater level measurements were made for bore 17796 over the period from March 1960 through July 1996. This bore screens the Precipice Sandstone approximately 13.6 km south of Glebe Weir, along Bullock Gully. The artesian head in this bore increased only slightly from 31.89 m above ground to 32.38 m above ground over the monitoring period, suggesting a relatively stable pressure condition in the Precipice Sandstone in this area. Bores 13030796, 13030797, 13030798 and13030799 are screened in the Precipice Sandstone located 1 to 2 km downstream of the dam site. Over the monitoring period on 1994 to 2003, the groundwater level fluctuated less than 0.5 m over the five recorded measurements for each bore. This indicates that groundwater levels in the Precipice Sandstone remain relatively stable in the vicinity of the dam site.

15.1.3.6. *Water table mapping*

A depth to water table map was compiled for the dam and surrounds using derived secondary variables from the project Digital Elevation Model (DEM). The mapped surface in Figure 15-2 is presented in five categories, ranging from < 5 up to > 50 m.

To produce the depth to water table surface a number of modelled surfaces were compiled and then calibrated against the available bore data to determine the modelled surface that best reflects the actual data. The underlying hypothesis to the method is that in unconfined aquifers flowing under topographic gradients, the water table is a smoothed and subdued reflection of topography (Desbarats *et al*., 2001). That is, the water table will be proportionally deeper under locally higher topographic features. Based on this technique, a shallow groundwater table (< 5 m) is generally encountered along and in association with drainage lines.

15.1.3.7. *Groundwater flow*

Regional groundwater flow patterns suggest that recharge to the Precipice Sandstone occurs in the outcrop areas located to the far west and north of Taroom. Regional groundwater flow in the Precipice Sandstone is to the south-east, towards the low-lying areas associated with the Dawson River.

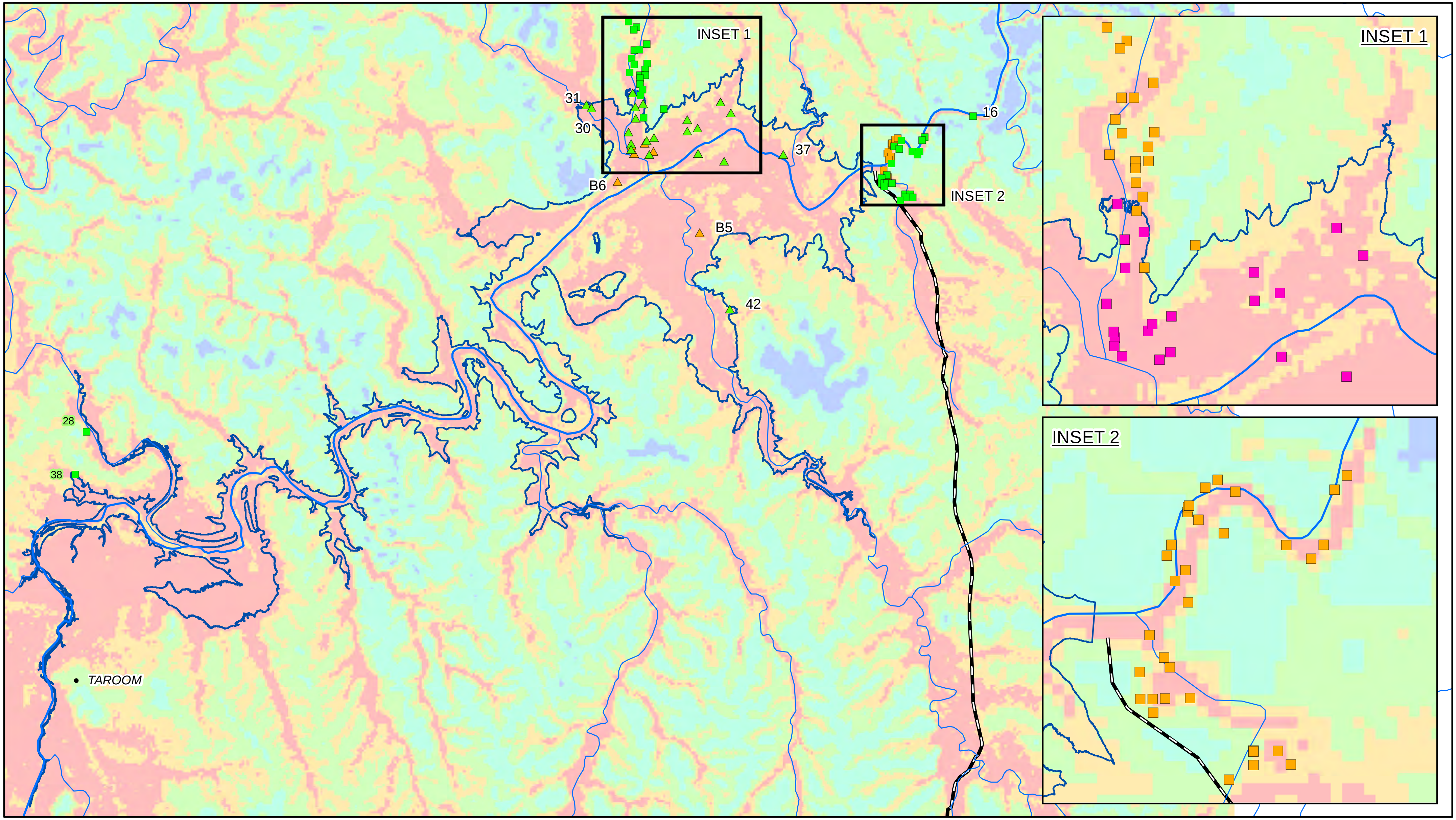
Figure 15-3 shows the potentiometric surface map of the Precipice Sandstone in the vicinity of the dam and surrounds. This map shows that localised groundwater recharge is occurring in the outcrop area to the east of the dam site and suggests a generalised south-west and north-west flow direction from the outcrop areas, towards the Dawson River.

There is also a groundwater depression centred on Taroom, likely as a result of groundwater extraction for town water supply.

Regional groundwater flow patterns for the Hutton Sandstone suggest a generalised south easterly flow direction from the outcrop areas to the north and west, towards the Dawson River. The potentiometric surface map of the Hutton Sandstone in the vicinity of the dam and surrounds (see Figure 15-4) suggests a generalised south-west and north-west flow direction from the outcrop areas to the east of the dam site, towards the Dawson River.

Groundwater flow direction in the alluvium of the Dawson River will be predominantly in a broad down-valley direction except for minor local flow pattern modifications associated with bores pumping from the alluvium and the presence of Glebe Weir. Flows are likely to be constrained to higher permeability pathways where non-cemented and open matrix sands and gravels are present, rather than through the entire cross sectional area of alluvium.

There is limited data and information on the interactions of groundwater between the Alluvial aquifer and the adjacent or underlying aquifers of the Surat Basin. It is expected that on the alluvium margins, lateral groundwater flow to the Alluvial aquifer from adjacent aquifers is likely.



LEGEND

- Town
- Proposed Pipeline
- Dawson River
- Watercourse
- Full Supply Level (183.5m AHD)

CEPLA GAB Spring Sites

- Inside FSL
- Outside FSL

Fensham GAB Spring Sites

- Outside FSL
- Inside FSL

Water Table Depth (m)

- < 5
- 5 - 10
- 10 - 20
- 20 - 50
- > 50

Projection: GDA94 Zone 56

Figure 15-2

0 1 2 4 Kilometres

N

Scale 1:200,000 (at A4)

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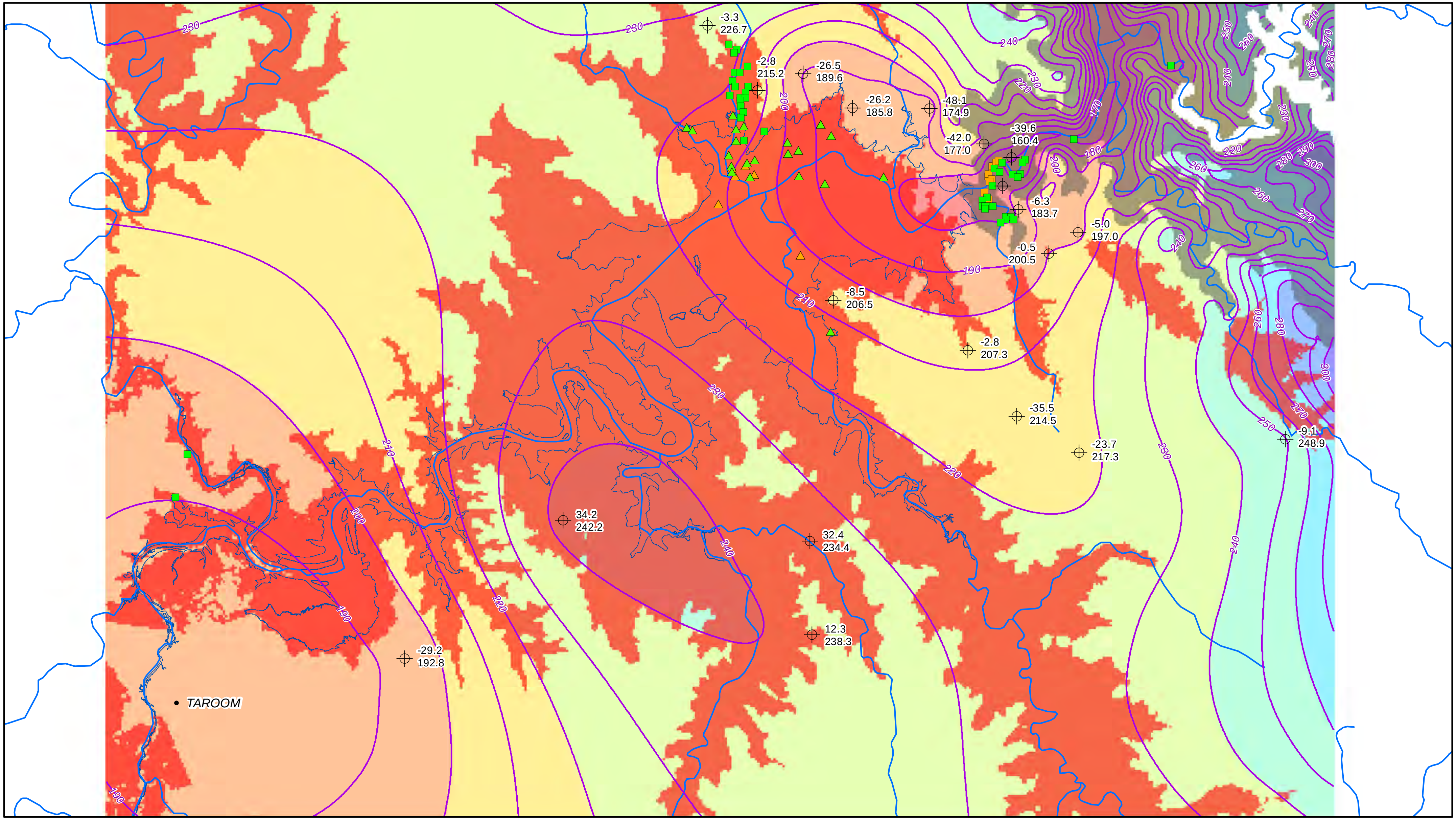
NATHAN DAM AND PIPELINES EIS

Water table depth for dam and surrounds



LEGEND

- Town
- Groundwater Bore (swl/rwl)
- Watercourse
- Full Supply Level (183.5m AHD)
- Precipice Sandstone Outcrop
- Artesian Area

CEPLA GAB Spring Sites

- Inside FSL
- Outside FSL

Fensham GAB Spring Sites

- Outside FSL
- Inside FSL

Elevation (m AHD)

- Absent
- < 180
- 180 - 200
- 200 - 220
- 220 - 240
- 240 - 260
- 260 - 280
- 280 - 300
- > 300

Projection: GDA94 Zone 56

Figure 15-3

0 1 2 4 Kilometres

N

Scale 1:200,000 (at A4)

SKM SunWater Making Water Work

NATHAN DAM AND PIPELINES EIS

Potentiometric surface map of the Precipice Sandstone

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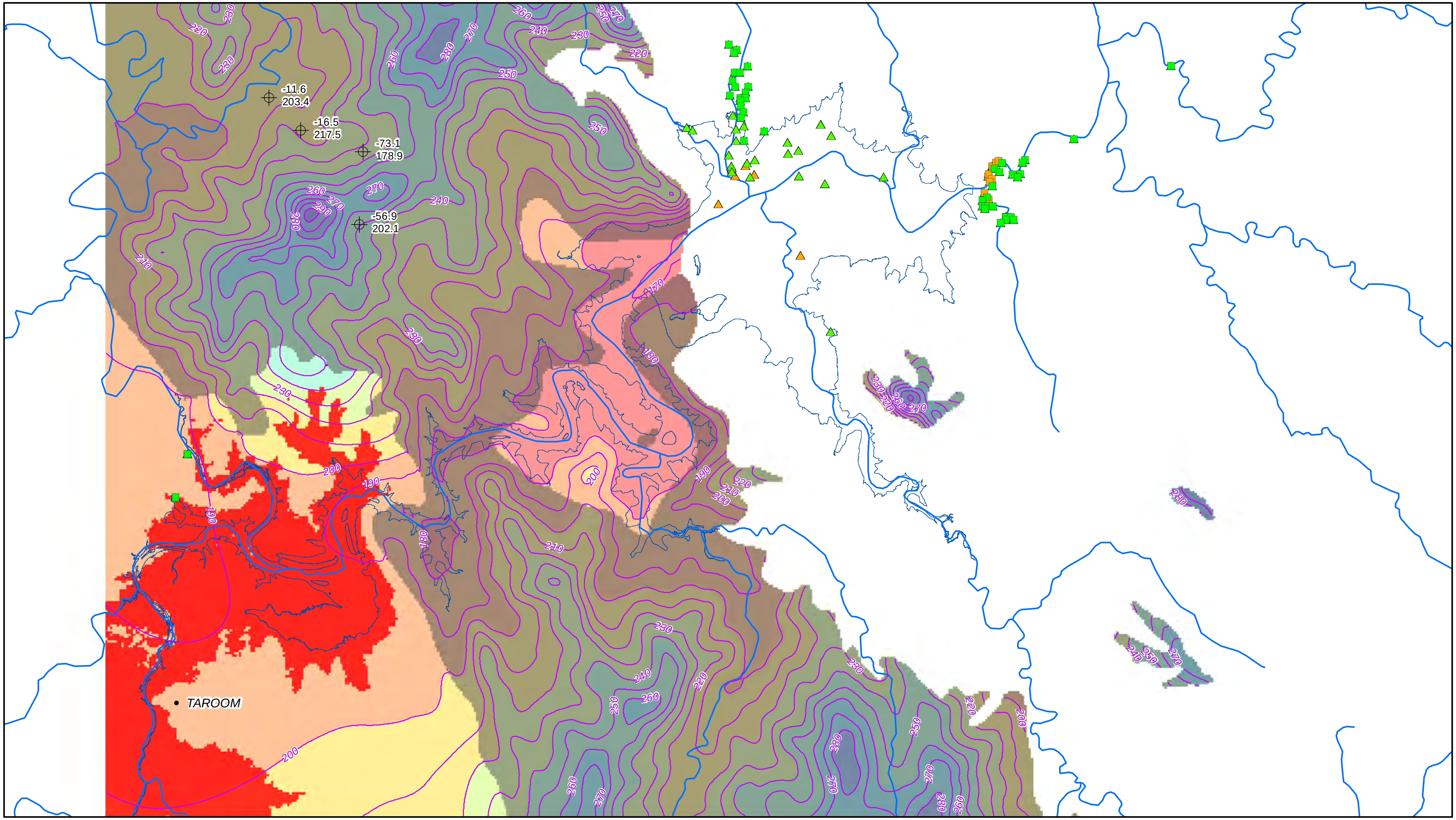

LEGEND

- Town
- Groundwater Bore (swl/rwl)
- Watercourse
- Full Supply Level (183.5m AHD)
- Hutton Sandstone Outcrop
- Artesian Area

CEPLA GAB Spring Sites

- Inside FSL
- Outside FSL

Fensham GAB Spring Sites

- Outside FSL
- Inside FSL

Elevation (m AHD)

- Absent
- < 180
- 180 - 200
- 200 - 220
- 220 - 240
- 240 - 260
- 260 - 280
- 280 - 300
- > 300

Projection: GDA94 Zone 56

Figure 15-4

0 1 2 4
Kilometres

N

Scale 1:200,000 (at A4)

SKM SunWater Making Water Work

NATHAN DAM AND PIPELINES EIS

Potentiometric surface map of the Hutton Sandstone

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15.1.3.8. *Groundwater yields*

Summary statistics for the bore yields by interpreted aquifer are provided in Table 15-3. More detailed information on individual bore yields for groundwater bores registered in the DERM database is provided in Appendix 15-B.

It is clear that the most productive of the aquifers is the Precipice Sandstone, with a mean recorded yield of 4.5 L/s. The data suggest that the Hutton Sandstone is generally only a moderate producer of water, notwithstanding that in some locations it does produce significant individual supplies.

Table 15-3 Summary details of reported individual bore yields

Aquifer	Number of recorded yield values	Minimum recorded yield (L/s)	Mean recorded yield (L/s)	Median recorded yield (L/s)	Maximum recorded yield (L/s)
Alluvium	0	n/a	n/a	n/a	n/a
Birkhead Formation	11	0.01	1.6	0.25	13
Eurombah Formation	6	0.13	1.9	1.5	3.9
Hutton Sandstone	39	0.01	1.1	0.76	5.6
Evergreen Formation	23	0.01	1.2	0.13	13
Precipice Sandstone	96	0.01	4.5	2.5	44

15.1.3.9. *Groundwater quality*

The electrical conductivity (EC) and pH of the groundwater system was assessed based on data from the DERM groundwater database. Available data has been compared to the following guidelines:

- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000* – Irrigation and general water quality, livestock drinking water quality (ANZECC Guidelines); and
- Australian Drinking Water Guidelines 2004 (ADW Guidelines).

Summary statistics for groundwater EC and pH sorted by the interpreted aquifer screened are provided in Table 15-4 and Table 15-5. More detailed information on individual bore yields for groundwater bores registered in the DERM database is provided in Appendix 15-B. There was no EC or pH data available for the Eurombah Formation.

Table 15-4 Summary statistics for groundwater electrical conductivity (μS/cm)

Aquifer	Number of samples	Minimum	Mean	Maximum
Alluvium	3	280	5933	16900
Birkhead Formation	10	1050	2155	3050
Eurombah Formation	0	NA	NA	NA
Hutton Sandstone	31	150	2059	4800
Evergreen Formation	4	158	1682	6000
Precipice Sandstone	279	102	359	14000

Table 15-5 Summary statistics for groundwater pH

Aquifer	Number of samples	Minimum	Mean	Maximum
Alluvium	3	6.1	7.0	7.8
Birkhead Formation	7	7.3	8.0	8.4
Eurombah Formation	0	NA	NA	NA
Hutton Sandstone	29	6.0	7.8	8.5
Evergreen Formation	4	6.5	7.3	8.1
Precipice Sandstone	241	5.8	7.5	12.2

In addition to the data from the DERM groundwater database, Quarantotto (1989) reported the following ranges for groundwater salinity in the key relevant formations within the Surat Basin:

- Hutton Sandstone: 70 to 4,485 mg/L TDS (117 to 7,475 µS/cm);
- Evergreen Formation: 97 to 754 mg/L TDS (162 to 1,257 µS/cm); and
- Precipice Sandstone 61 to 555 mg/L TDS (102 to 925 µS/cm).

It was noted however that approximately 74% of salinity observations for the Hutton Sandstone were less than 1,700 µS/cm. In addition, Quarantotto (1989) noted low (< 250 µS/cm) salinity levels in the area around Taroom and Glebe Weir for the Precipice and Hutton Sandstones.

Alluvium

Salinity data from bores constructed in the Alluvial aquifer is quite variable, based on the very limited number of samples. Of the two bores sampled in the Dawson River alluvium (13030380 and 13030381) the EC was 16,900 µS/cm and 280 µS/cm respectively. Based on one sample in the Cockatoo Creek alluvium (47330), the EC is 620 µS/cm. The pH ranged from 6.1 to 7.8, with a mean of 7.

According to the ANZECC Guidelines, the required EC for no loss of production ranges from <3,000 µS/cm for the most salt sensitive animals (poultry) up to <7,500 µS/cm for sheep. For crop types the salinity tolerances range from <950 µS/cm for sensitive crops up to <12,200 µS/cm very tolerant crop types. Based on the limited number of samples, the groundwater from the Alluvial aquifer appears to be generally suitable for livestock consumption and all crop types (except for bore 13030380).

Birkhead Formation

The EC data from bores constructed in Birkhead Formation ranges from 1,050 to 3,050 µS/cm, with a mean EC of 2,155 µS/cm. This suggests that the groundwater from the Birkhead Formation is typically suitable for livestock use and moderately tolerant crop types, but is not suitable for human consumption (< 1500 µS/cm). The pH ranges from 7.3 to 8.4, with a mean of 8; hence the groundwater is typically slightly alkaline.

Hutton Sandstone

The EC data from bores constructed in Hutton Sandstone ranges from 150 to 4,800 µS/cm, with a mean EC of 2,059 µS/cm. This suggests that the groundwater from the Hutton Sandstone is fresh to slightly brackish and is generally suitable for livestock use and moderately tolerant crop types. The mean groundwater salinity from the Hutton Sandstone is above ADW Guidelines for acceptable drinking water quality (1,500 µS/cm) and hence the groundwater is not considered suitable for human consumption. The pH ranges from 6.0 to 8.5, with a mean of 7.8; hence the groundwater is typically slightly alkaline.

Evergreen Formation

The EC data from bores constructed in Evergreen Formation ranges from 158 to 6,000 µS/cm, with a mean EC of 1,682 µS/cm. This suggests that the groundwater from the Evergreen Formation is typically suitable for livestock use and moderately sensitive crop types, however is typically not suitable for human consumption. The pH ranges from 6.5 to 8.1, with a mean of 7.3; hence the groundwater is typically neutral.

Precipice Sandstone

The EC data from bores constructed in Precipice Sandstone ranges from 102 to 14,000 µS/cm, with a mean EC of 359 µS/cm. Although the groundwater salinity can be quite variable within the Precipice Sandstone, it is typically fresh. As such, the majority of bores are suitable for livestock use and all crop types, and the groundwater is considered suitable for human consumption. The pH ranges from 5.8 to 12.2, with a mean of 7.5. This suggests that the groundwater is typically neutral, and generally within the ADW Guideline values of 6.5 to 8.5.

The general chemical characteristics of the groundwater are (Quarantotto 1989):

- sodium is the dominant cation for the Hutton Sandstone, whilst chloride is the most common anion, followed by bicarbonate and sulphate;
- for the Boxvale Sandstone Member of the Evergreen Formation, bicarbonate dominant anion waters are the most common with the remainder being either chloride or bicarbo-chloride types, whilst sodium is the dominant cation, followed by calcium and magnesium; and
- for the Precipice Sandstone, sodium is the dominant cation, followed by calcium and magnesium, whilst bicarbonate is the dominant anion followed by chloride and sulphate.

DNR (1996) also indicated that the Precipice Sandstone waters can be grouped into two broad types namely:

- a sodium and bicarbonate dominated water which is found in the majority of water bores; and
- a sodium-chloride-bicarbonate water (largely confined to the left bank of the Dawson River in the Glebe Weir/Nathan Gorge area).

DNR (1996) suggested that the there were some limitations on the use of Precipice Sandstone groundwater for domestic use, citing occurrence of high levels of iron and very low pH. A program of targeted sampling of groundwater bores and GAB springs was undertaken by DNR (1996) as part of an assessment of the impact of the then Nathan Dam. This data is presented in Table 15-6. The results indicate that there is potential for the Precipice Sandstone to host some very elevated groundwater iron concentrations (up to 40.5 mg/L), however the minimum recorded groundwater pH was only 5.5.

Table 15-6 Summary of details for groundwater analyses undertaken for Nathan Dam project (modified after DNR, 1996)

Region	Sample source	Interpretation of aquifer tapped by bore	Sample identifier	pH	Electrical conductivity (mS/cm)	Silica (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Sulphate (mg/L)	Iron (mg/L)	Manganese (mg/L)
	Spring	NA	Boggomoss 5	6.5	200	15	31	5.4	4.2	1.4	23.5	48	< 2	NA	NA
	Spring	NA	Boggomoss 11	6.8	200	11	31.5	3.6	5.1	1.7	33	42.5	< 2	NA	NA
	Spring	NA	Boggomoss 56	6.4	220	11	32	3.5	7.1	2.1	34	50	< 2	NA	NA
	Bore	Precipice Sandstone	35740	6.1	335	10	51	6.1	9.1	2.4	70	61	< 2	40.5	0.47
	Bore	Precipice Sandstone	14963	6.1	105	11	19	2.3	2.5	0.8	32.5	18.5	< 2	2.5	0.03
	Bore	Precipice Sandstone	35256	5.9	220	11	32	3.3	7	2	35.5	51	< 2	3.6	0.09
	Bore	Not defined	13438	6	175	12	25.5	4.1	5.9	1.6	30	37.5	< 2	NA	NA
	Bore	Precipice Sandstone	14871	6.3	155	12	26	3	3.6	1.2	31	30.5	< 2	6.5	0.07
	Bore	Precipice Sandstone	89562	6.5	340	12	59	6.1	6.3	2.2	80	65	< 2	11	0.13
	Bore	Precipice Sandstone	89561	6.5	190	10	29.5	2.5	5.8	1.8	32	44	< 2	NA	NA
Boggomoss Ck	Surface water	NA	Spring Ck	7	295	6	46.5	4.6	8.3	3	52	63	7.8	NA	NA
	Spring	NA	Boggomoss 26	7.2	2000	9	460	2.7	8.9	2.6	435	440	6.8	NA	NA
Palm Tree Ck	Spring	NA	Boggomoss 38	8.2	1050	13	220	0.6	2.4	0.2	210	215	< 4	NA	NA
	Spring	NA	Boggomoss 4	7.3	305	11	67	2.7	5.3	0.9	170	14.5	< 2	NA	NA
	Bore	Precipice Sandstone	67280	5.5	155	11	38	1.9	1.4	0.4	94	6	< 2	1.1	0.03
	Bore	Precipice Sandstone	17070	6.7	130	14	30.5	1.9	1	0.3	70	7.8	< 2	1.1	0.02
Price Creek	Bore	Precipice Sandstone	89541	7.2	140	14	32	1.8	0.8	0.3	73	9	< 2	13.5	0.04
	Bore	Precipice Sandstone	32735	7.4	145	18	32.5	2.1	1.2	0.3	73	9.9	< 2	NA	NA
Upper Cockatoo Ck	Spring	NA	B38658	7.2	300	12	70	2.3	2.3	0.3	180	9	< 2	NA	NA

15.1.3.10. Groundwater use

There are a number of existing groundwater facilities that provide water for town water supply, irrigation, stock and/or domestic use. The location of authorisation to take groundwater registered on the DERM Water Entitlement System in the vicinity of the proposed Nathan Dam and its water storage area are shown in Figure 15-5. Summary details for the groundwater bores are provided in Appendix 15-B and a summary of the authorisations for taking of groundwater in the area are given in Appendix 15-D.

The main authorisations to take groundwater include:

- a 500 ML/a entitlement from the Precipice Sandstone for the purposes of the Taroom Town Water supply;
- a 200 ML/a authorisation for urban supply from the Precipice Sandstone for the purposes of the Taroom Town Water supply;
- a 200 ML/a authorisation for urban supply from the Precipice Sandstone for the purposes of the Taroom Town Water supply (currently under renewal);
- a 100 ML/a authorisation for irrigation use from the Precipice Sandstone, located approximately 5 km south-west of Glebe Weir;
- a 74 ML/a authorisation for domestic and irrigation use from the Precipice Sandstone, located on the left bank of the Dawson River immediately adjacent to Glebe Weir;
- a 74 ML/a authorisation for irrigation use from the Hutton Sandstone on Lot 1 LE269 located near the intersection of the Leichhardt Highway and Glebe Weir Road approximately 23 km north-north-east of Taroom; and
- a 20 ML/a authorisation from the Hutton Sandstone for domestic and stock use, located approximately 2 km north-east of Taroom.

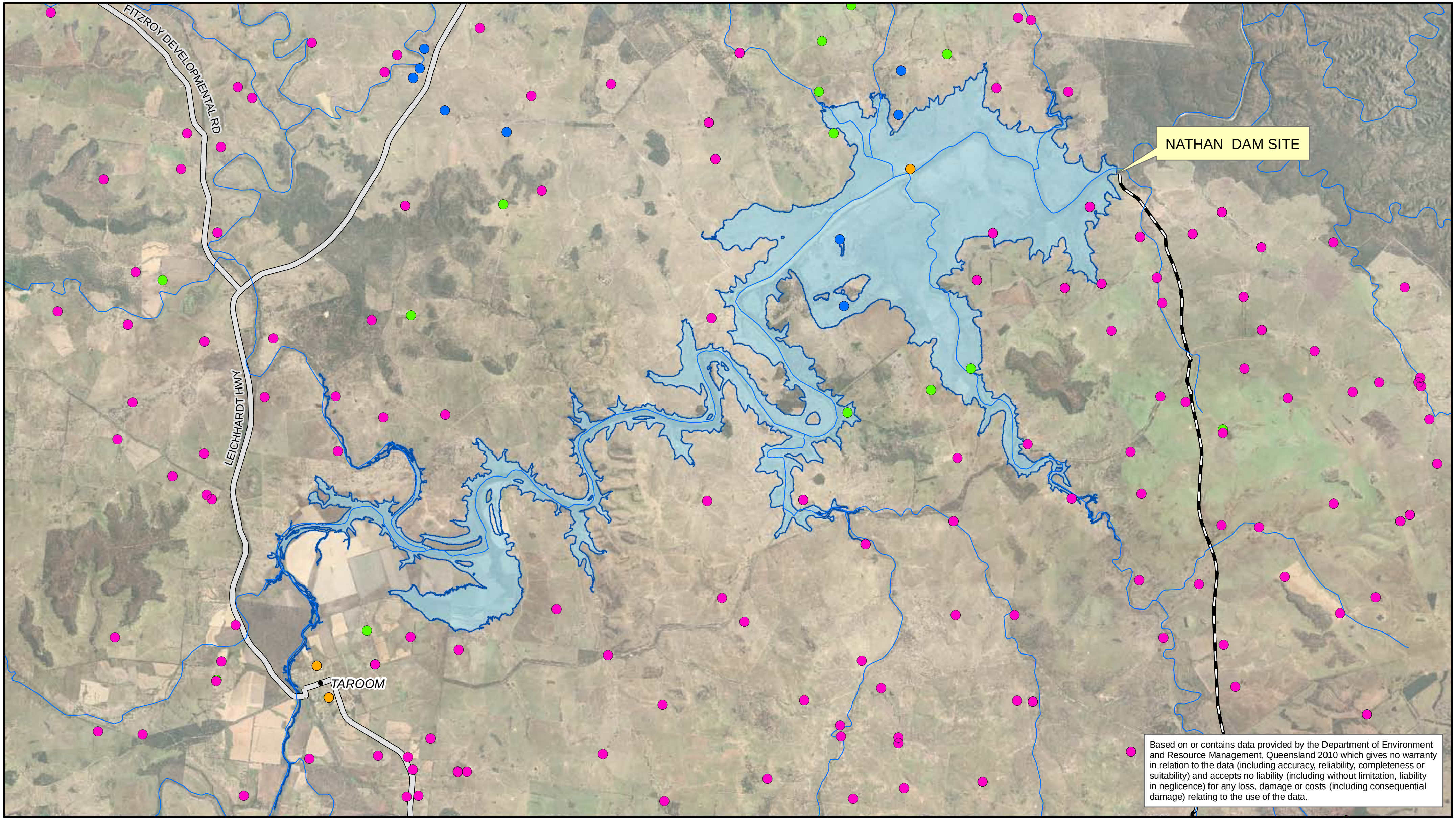
Groundwater allocation by sector is shown in Table 15-7 and entitlements by aquifer is summarised in Table 15-8. It is apparent that over 90% of allocated groundwater used within the Project area is sourced from the Precipice Sandstone Aquifer.

Table 15-7 Groundwater entitlements by sector

Sector	Entitlement (ML/year)
Town Water Supply	900
Stock and Domestic	20
Irrigation	248

Table 15-8 Groundwater entitlements by aquifer

Aquifer	Entitlement (ML/year)	Percentages (%)
Precipice Sandstone	1074	92%
Hutton Sandstone	94	8%



LEGEND

- Towns
- Proposed Pipeline
- Watercourse
- State Controlled Roads
- Full Supply Level (183.5m AHD)

Existing Groundwater Users

- Irrigation
- Stock / Domestic
- Unknown
- Urban

Projection: GDA94 Zone 56

Figure 15-5

0 1 2 4
Kilometres

N

Scale 1:200,000 (at A4)

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NATHAN DAM AND PIPELINES EIS

Authorisation to take groundwater (DERM Water Entitlement System, 26 July 2010)

15.1.3.11. Interaction with surface water

Groundwater and surface water connectivity

Forbes (1968) noted that the Dawson River is fed by springs and that this contributes to permanent flow. Forbes also noted that springs are common in the creeks cutting the Precipice Sandstone and in many places these creeks are perennial.

DNR (1996) noted the following specific stream gauging information related to groundwater baseflow:

- a baseflow discharge of 6.1 L/s measured on 13 August 1996 in Cabbage Tree Creek approximately 250 m upstream of the inundation area of Gyranda Weir (latitude 25º25'50" longitude 150º10'10");
- a baseflow discharge of 11 L/s measured on 14 August 1996 in Price Creek (latitude 25º28'07" longitude 150º07'01"); and
- a baseflow discharge of 3.17 L/s measured on 14 August 1996 in Price Creek near its junction with the Dawson River (latitude 25º27'11" longitude 150º09'14").

Groundwater recharge and discharge

The regional groundwater flow pattern indicates that recharge to the Precipice Sandstone occurs in the outcrop areas located well to the west and north of the dam site and that groundwater flows largely to the south-east before discharging along the Dawson River and GAB springs. There is also localised recharge occurring via infiltration of rainfall on exposed outcrops of Precipice Sandstone on the flanks of the Dawson River valley (Figure 15-3).

Similarly, potentiometric surface mapping of the Hutton Sandstone (Figure 15-4) suggests that recharge occurs to the west and north of the dam site and that groundwater flows largely to the south-east before discharging along the Dawson River. There is also localised recharge via infiltration of rainfall on exposed outcrops of Hutton Sandstone on the flanks of the Dawson River valley.

A simplified approach was adopted in the groundwater modelling of the Project area to estimated recharge to the groundwater system through rainfall, pan evaporation and landuse. This is considered appropriate when developing a regional groundwater model within a region that has limited groundwater data. Recharge was assumed to occur when rainfall exceeded ¼ of pan evaporation (higher fractions of pan evaporation were tested but this only allowed recharge to occur on rare large rainfall events). Recharge was then calculated as 4% of rainfall minus ¼ of pan evaporation for dryland and irrigation (plus 0.1 mm/day for irrigation accessions where applicable). In the area where the outcropping precipice occurs it was necessary to increase recharge to 100% of rainfall minus ¼ of pan evaporation. The adoption of a simplified approach to evapotranspiration is not expected to have a significant impact on the modelling outcomes as the principal impacts of dam construction and operation relate to the transmission of pressures within the confined aquifer where evapotranspiration has little or no effect.

Recharge to the alluvium of the Dawson River would occur via a combination of mechanisms, including:

- direct infiltration of rainfall;
- infiltration of stream flow, particularly during flood periods; and

- upward leakage of artesian water from underlying Surat Basin formations.

Anecdotal evidence indicates that rate of discharge from the GAB springs in the lower section of Boggomoss Creek varies seasonally and from year to year based on overall rainfall, with wetter years producing greater discharge. The seasonal variation most likely reflects response to rates of evapotranspiration whilst the longer-term fluctuations would reflect both changes in annual rainfall and recharge to the source formations yielding the artesian flows.

Groundwater dependent ecosystems

Groundwater plays a critical part in maintaining the health and biodiversity of a variety of ecosystems. According to the *Australian Natural Resource Atlas 2005* the GAB Groundwater Management Unit (GMU), in which the dam and surrounds is situated, is recognised to contain Groundwater Dependant Ecosytems (GDEs).

DERM maintains the Queensland Springs Database which includes the springs identified by Fensham and Wilson (1997) and Fensham and Fairfax (2005). There were 73 springs within the Project area identified from the Queensland Springs Database (Version 5.0). Field investigations undertaken as part of the EIS, identified an additional 17 springs within the Project area (Chenoweth, 2010). A listing of all identified springs is included in Appendix 15-F.

The listing advice for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin and the Recovery Plan differentiate various types of GAB springs. As stated in the Recovery Plan, the community includes spring wetlands fed by discharge of GAB groundwater except where springs occur within outcrop areas of the following sandstone formations on the eastern margins of the GAB: Adori, Boxvale, Clematis, Expedition, Gilbert River, Griman Creek, Gubberamunda, Hampstead, Hooray, Hutton and Precipice sandstones, the Bulimba, Glenidal, Moolayember, Piliga, Rewan, Wallumbilla and Westbourne formations, and the Helby and Ronlow Beds (Fensham *et al*. 2010). Recharge springs are not included in the community. These springs are generally associated with outcropping sandstone, which can form rugged landscapes with springs often situated in gullies and providing the source for streams. Sodic and salty non-wetland areas, although intimately associated with spring wetlands, are also not included in the community, nor are springs within the GAB area with discharge emanating from Tertiary aquifers positioned above the GAB sequence (Habermehl 1982; Fensham *et al*. 2004a).

DNR (1996) undertook a review of the Boggomoss springs in the Dawson River area. The key points arising from this review included:

- many of the springs lie in a linear arrangement and appear to be fault controlled expressions of leakage of artesian water;
- springs occur in topographic low points where artesian water pressure may be most effective in forcing water to the surface;
- water chemistry of the springs is similar to that of nearby artesian bores;
- flow in the springs is believed to be continuous as water samples are low in conductivity (no flow would enable concentration of salts by evaporation);
- few of the springs generate appreciable surface flows away from their immediate mounds with the largest discharge measured being only 0.36 L/s although there was a report of a spring located outside of DNRs study area that flowed at approximately 1.5 L/s after major recharge events; and

- the springs are dynamic in that the outlets of the springs close over from time to time and new outlets then appear.

DNR indicated that of the Boggomoss springs they studied, all were associated with discharge from the Precipice Sandstone except for a series of springs located in the Palm Creek area approximately 10 km north north-west of Taroom. These springs were believed to be associated with groundwater discharge from the Hutton Sandstone / Eurombah Formation.

Figure 15-6 shows the Boggomoss springs in the vicinity of the dam and surrounds. The light pink area on the map shows the artesian area of the Precipice Sandstone. The dark pink area defines where the Precipice Sandstone unit is artesian by more than 5 m and the overlying Evergreen Formation is less than 60 m thick. As can be seen, there is a strong correlation between the locations of the springs overlying the dark pink area. This suggests that in addition to being fault controlled, the locations of the springs appear to also be controlled by the artesian pressure within the Precipice Sandstone and the thickness of the overlying aquitard.

DNR (1996) noted that in some areas, artesian bores had encountered abnormally shallow artesian water beds within the shales of the Evergreen Formation which is normally an aquitard. It was concluded that these artesian conditions were the result of faults allowing connection between the underlying Precipice Sandstone and the overlying Evergreen Formation. It was also noted that water could be seen leaking from fractures in rocks in the bed of Cockatoo Creek in its upper reaches near its junction with Rocky Creek. It was also noted that at the head of Nathan Gorge water is present in the bed of the river (above the flow channel) as clear pools and there is no seepage present in the sandstone walls. However, further downstream in the Nathan Gorge and its tributaries seepage is evident in the walls as well as in the bed of the river.

Another type of GDE, 'Stygofauna', is defined by Gibert *et al*. (1994) as obligate groundwater fauna. Based on a review of the publically available literature, there are no recorded occurrences of stygofauna within the Project area. Relatively few records of stygofauna surveys conducted within Queensland were located. The nearest locations at which stygofauna have been collected are the Burnett aquifer near Bundaberg (Hancock and Boulton, 2008), the Pioneer aquifer near Mackay (Hancock and Boulton 2008), and an unknown aquifer situated near Collinsville (C. Foord, pers. comm.). Although not publically available, records of stygofauna surveys conducted within the region relevant to the Project area may exist in the form of consultancy and governments reports, other grey literature or in individual researchers' records (Tomlinson and Boulton, 2008).

As the Project area has not been surveyed for stygofauna, it cannot be definitively concluded that no stygofauna communities are present with the Project area. Indeed, the fact that stygofauna have been observed to inhabit aquifers in other regions of Australia (predominantly from Western Australia) with similar water quality characteristics (EC, DO, pH and water temperature) as that observed within the Project area (Hancock and Boulton, 2008; Humphreys, 2008) suggest that stygofauna may be present .

Sections 10 to 14 identify existing flora and fauna habitats within the Project area, including a description of the aquatic and terrestrial flora and fauna that may be impacted by the Project.

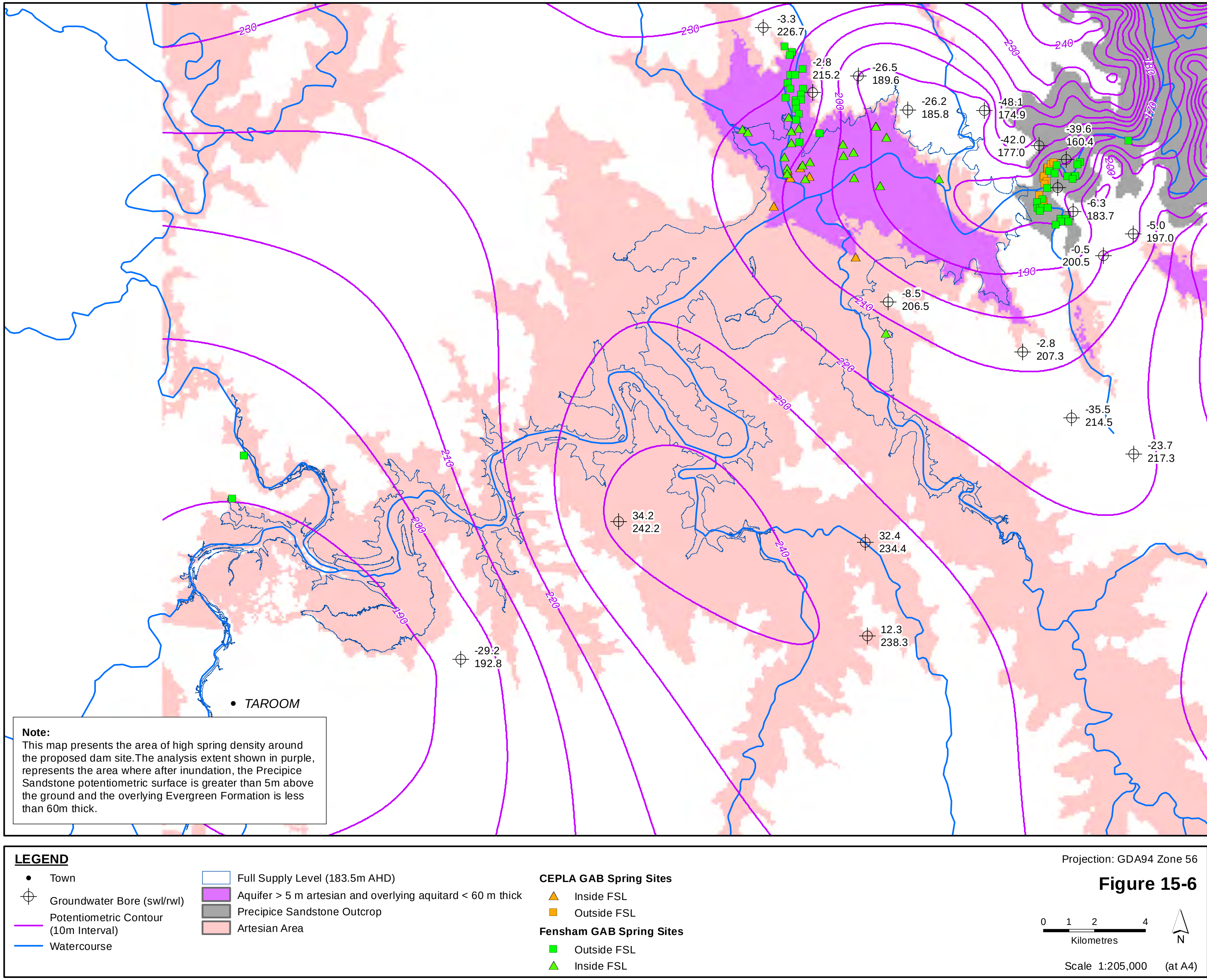

Figure 15-6

NATHAN DAM AND PIPELINES EIS

Location of Boggomoss spring sites and artesian extent of the Precipice Sandstone aquifer

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15.1.3.12. Vegetation clearing, sedimentation and salinity

Vegetation clearing is discussed in detail in Chapter 10 and sedimentation is discussed in Chapter 14. There is unlikely to be any significant impacts from vegetation clearing or sedimentation on the local groundwater resources.

There are a number of mechanisms by which groundwater salinisation could occur as a result of the dam. These include:

- increased recharge leading to leaching of saline soil water towards fresher groundwater; and
- rising water tables causing groundwater to be mixed with more saline soil water.

Soil salinity in the Project area is discussed in Chapter 6. The following conclusions were made in regard to salinity:

- although it is estimated that more than 80% of the water storage is cleared or has had most of the tree and shrub vegetation removed, there are no known outbreaks of salinity. Most of the vegetation clearing was undertaken more than 30 yrs ago so it is likely that salinity outbreaks would have occurred in any high hazard areas by now. No salinity outbreaks are expected to result from clearing and inundation of the water storage or clearing of the works area;
- during operations, the water storage area and immediate surrounds, the dam site, and downstream areas will be monitored to detect any instances of erosion, salinity, or other landscape instability so that any necessary remedial work can be arranged;
- no outbreaks of salinity or non-saline seepage have been observed along the pipeline route. Salinity is not expected to occur as a result of pipeline construction or operation and non-saline seepages should not occur provided that precautions are undertaken such as using clay, sand bags or concrete to create collars around the pipe to prevent down-slope movement of water in the bedding material with subsequent discharge in footslope areas. The extent of any clearing that may be required for the pipeline is extremely unlikely to be sufficient to cause salinity outbreaks; and
- no salinity was observed in the vicinity of areas where road construction will take place and none is expected to occur as a result of the works proposed.

15.1.3.13. Groundwater use by the Project

The use of groundwater for on-site purposes (such as dust suppression, etc.) has not been identified as a requirement for pre-construction, construction, and operational phases of the Dam. Generally, water for construction is to be drawn from the Dawson River and tributaries and the Condamine River and tributaries under permit. Water for dust suppression, haul roads and rehabilitation is proposed to be sourced from retention ponds or otherwise drawn directly from the Dawson River. Groundwater discharge from dewatering bores will be pumped to a sedimentation pond on the left bank of the river. The water retained in sedimentation ponds is to be used to irrigate drying springs (if required), used on the construction site where possible, or progressively released back into the river under a water quality management plan.

15.1.4. Pipeline

The pipeline route from Nathan Dam to Dalby crosses a number of sedimentary geological units ranging in age from Quaternary to Jurassic. The geology of the pipeline route has been described in Chapter 6 to cross the following geological units:

- Quaternary alluvium – this is most commonly clay, particularly in the portions of the route east of Miles;
- Chinchilla Sand – this unit is predominantly sand grading into granule conglomerate and sandy clay and it occurs south-east of Chinchilla;
- Kumbarilla Beds – this unit is predominantly sandstone, siltstone and mudstone and the main occurrences are between the Great Divide and Chinchilla;
- Injune Creek Group – this unit is predominantly comprised of calcareous lithic sandstone, siltstone and mudstone and occurs from approximately 38 km north-north-east of Wandoan almost to the Great Divide, interrupted by minor areas of Quaternary alluvium;
- Hutton Sandstone – this unit is predominantly coarse-grained and occurs from Cockatoo Creek south to approximately 38 km north-north-east of Wandoan; and
- Evergreen Formation – this unit is predominantly comprised of labile and sublabile sandstone, carbonaceous mudstone, and siltstone and occurs from north of Cockatoo Creek almost to the dam site.

More detail of the geological units along the pipeline route is provided in Chapter 6. The spatial distribution of these units is shown in Figure 6-6.

The pipeline route intersects the Precipice Sandstone in the immediate vicinity of Nathan Dam only. Once it is out of the river bed, the pipeline and associated infrastructure will be on the right bank of the Dawson River, with the riverbed providing a discontinuity in the Precipice Sandstone beds that dip to the south-west.

The areas where the pipeline route crosses the Hutton Sandstone, and other Jurassic sedimentary units, are generally gently undulating to rolling topography (Chapter 4) so that shallow aquifers would be expected to come to the surface in lower parts of the landscape. There are no springs or seeps in the vicinity of the pipeline route so groundwater is not expected to be encountered in these units.

Groundwater in the Pliocene, Cainozoic and Quaternary deposits is likely to be considerably deeper than the depth of excavation for pipeline construction (maximum depth of disturbance 2.5 m). There is however a possibility that groundwater will be encountered below stream channels. If this occurs, small volumes may need to be pumped from the trench. Because this will be near-surface water, associated with present streams, quality should be good and disposal downstream will not pose a threat to the environment. The volumes involved will be very small and will not threaten the aquifer.

Perched water tables may be encountered in lower parts of the topsoil of some texture contrast soils if construction takes place during prolonged periods of wet weather however, this water will be associated with the soil profile, not groundwater systems.

Soils along the pipeline route are generally clays, or have clay subsoils that will protect aquifers from any pollution from contaminants that may be associated with pipeline construction. Areas where aquifers are most vulnerable to contamination are stream beds, the Cainozoic sand plains and the Pliocene Chinchilla Sand.

15.1.5. Associated infrastructure

Chapter 2 describes the detail of the associated infrastructure related to the Project. Areas where road works are to take place are in, or in the vicinity of the water storage area and groundwater conditions will be similar to those described for the relevant geological units in and around the dam. Geology along most of the route of the proposed Spring Creek Road extension to the dam site is Evergreen Formation, predominately comprised of sandstone and mudstone. The southern access road from the Taroom – Cracow Road traverses Evergreen Formation, Quaternary alluvium and Precipice Sandstone near the dam site (refer Figure 6-2). Excavations for road works will be shallow. As such, groundwater impacts are unlikely. There are nine potential clay borrow areas, all of which occur within close proximity to the proposed Nathan Dam. The areas would not be excavated any further than 5 m. As such, groundwater impacts are again unlikely.

15.2. Potential impacts and mitigation measures

A quantitative assessment of potential impacts to groundwater from the Project has been undertaken. The objective of the impact assessment is to evaluate groundwater related risks from the Project; specifically to:

- identify potential impacts on the objectives and requirements of the WRP and ROP;
- identify activities that have the potential to impact groundwater;
- provide an indication of groundwater risk and vulnerability to construction and operational activities;
- prioritise high-risk activities and identify site-specific field investigations that might be required to further evaluate specific risks; and
- define management activities that could be implemented to minimise or mitigate risks to groundwater.

The identified project activities which pose a potential risk to groundwater include:

- decreased groundwater levels associated with dewatering;
- disposal of dewatered groundwater;
- decreased groundwater levels downstream of the dam as a result of dam wall construction and grouting;
- increased groundwater levels associated with dam inundation;
- changes in groundwater salinity; and
- groundwater contamination.

15.2.1. Water Resource (GAB) Plan and GAB ROP

Although extraction of groundwater has not been proposed for on-site purposes (e.g. dust suppression.), groundwater extraction bores will be required to facilitate dewatering activities. An application will be required for a development permit to construct the extraction bores and for a water permit to temporarily extract water.

Application of the GAB ROP effectively precludes the granting of licenses for new bores (or increases from existing bores) in areas within 5 km of a GAB spring, from management units in connection to that spring. In addition, a decision about a water licence cannot be made if that decision will result in the cumulative 'spring factor' for the spring exceeding 400 millimetres. That is, if the cumulative impact beneath the spring on subartesian water levels or artesian pressure associated with a decision about a water licence(s) exceeds 400 mm. The plan contains an attachment that enables calculation of a 'spring factor' to determine water level impact at a spring, based on the proposed groundwater pumping rate, the aquifer transmissivity and its separation distance from the subject spring.

Given that there are numerous GAB springs within a 5 km radius of the dam site, these restrictions will apply to licenses for dewatering bores to support the Project. According to section 40 of the ROP however, a water licence may be approved if the proposed decision will not negatively impact on the outcomes of the WRP. Alternatively, under Section 237 of the *Water Act,* an application can be made for a water permit for taking water for an activity if that activity has a reasonably foreseeable conclusion date.

With respect to the potential for increases to groundwater levels associated with a dam inundation, although no approvals for the construction of the dam are required under the GAB WRP, the Great Artesian Basin ROP has identified a performance standard of the maintenance of groundwater levels at artesian springs within a 400 mm range.

It is considered that all significant groundwater impacts identified that arise from the dam construction and operational phases can be addressed through implementation of appropriate management activities. These will be addressed in the following sections.

15.2.2. Nathan Dam groundwater model

The purpose of this section is to assess the potential impact of Nathan Dam on the groundwater system, so that appropriate mitigation measures can be proposed that meet State and Federal Government requirements. This was achieved through development of a groundwater model.

A finite element modelling code (Feflow) was used to construct the Nathan Dam groundwater model. Previous modelling work at the site has been undertaken in the finite difference modelling code (Modflow). The key reasons for the change to a finite element approach are outlined below:

- finite element models enable the user to refine the mesh around specific areas of interest (e.g. Boggomoss springs). This enables the creation of fine spatial detail around the springs whilst maintaining a coarse mesh elsewhere. This is ideal for minimising model run times whilst not compromising detail where it is required;
- the ability to specify nodal locations enables explicit representation of each individual spring within the model domain as its own model node (as opposed to lumping springs into a series of coarse grid cells); and
- the Feflow package has proven to be numerically more stable in conditions where the watertable crosses through multiple geological layers, as is the case in this region.

The Nathan Dam groundwater model was constructed as a 5 layer, three-dimensional groundwater model. These layers represent the major aquifers of the region. The 5 model layers were as follows:

1) Alluvium;
2) Injune Creek Group (Confining Unit);
3) Hutton Sandstone;
4) Evergreen Formation (Confining Unit); and
5) Precipice Sandstone.

Mapped outputs for each modelled layer were in turn used to identify potential impacts to associated GDE's and groundwater users.

15.2.2.1. Modelled Scenarios

Four scenario models were compiled in order to assess the potential impacts of Dam construction and operation against the ToR. The four scenarios were as follows:

- Scenario 1 –the dam at full supply level for the duration of the model run;
- Scenario 2 –the dam at median supply level for the duration of the model run;
- Scenario 3 – simulating the dewatering during the construction phase of the dam wall; and
- Base Case – no dam.

Each scenario (except scenario 3) was run as a repeat of 1900 to 2008 historical conditions, consistent with the hydrological modelling "extended simulation period" scenario.

The full supply level scenario can be considered a maximum impact scenario where the dam is maintained at full supply (183.5 mAHD) for an extended period. It should be noted however that in reality this scenario is only expected to occur 7% of the time. The Median supply level scenario was modelled in exactly the same way as the full supply level scenario. The median supply level was 181.7 m AHD as per the hydrological modelling "extended simulation period" scenario.

In scenario three the model was refined to enable the assessment of the likely impacts of dewatering during the construction phase of the dam. Based on the description of the Project (Chapter 2) and discussion with SunWater, it was understood that dewatering was to occur for approximately a 50 day period during the installation of the chimney filter at the downstream toe of the dam wall. Dewatering was to occur to a depth of 3 m below the base of the chimney filter (3 m below the base of the river bed alluvium). This equated to an elevation of 142 mAHD, approximately 19 m below the normal river elevation. It was expected that dewatering would occur via 4 or 5 bores placed near the chimney filter. It was also assumed that during construction the river would be diverted via a constructed channel around the construction site between two coffer dams approximately 50 m upstream and downstream from either toe of the dam wall.

The base case scenario was used to compare the results of the other scenarios and therefore assess the impact of the dam. The only change from the calibration model was the conversion of the time-varying river levels on Dawson River to constant levels as per the long-term average. Climate inputs were derived from the hydrological modelling "extended simulation period" scenario. Groundwater extractions were maintained at current levels (as per the calibration model). No changes to model parameters were required.

15.2.2.2. Model Uncertainty

All groundwater models include a level of uncertainty and non-uniqueness. This uncertainty arises from the fact that not all complexities and features of a groundwater domain can truly be represented in fine detail by a mathematical model that subdivides the domain into discrete and interconnected elements. Model uncertainty can be reduced through an appropriate model calibration process in which the model is modified or refined in order to best match groundwater behaviour that has been observed in the past. The value of the calibration process and the degree to which it is able to reduce model uncertainty depends on the length of record of groundwater observation, the spatial density of observations and the different features of the system that have been observed and are replicated in the model.

The Nathan Dam groundwater model was calibrated against a measured and inferred potentiometric surface in the Precipice Sandstone and against measured spring flows. The model calibration period was selected as a 15 year period running from 1969 to 1984. This was originally selected due the available observation bore data. After the model was constructed and calibration commenced however it was quickly realised that there were obvious errors in the observation bore measurements that made them unsuitable for use during calibration. Consequently, the calibration turned its focus to calibrating against the inferred potentiometry (Figure 15-3 and Figure 15-4) and the estimated spring flow volumes provided by DERM (Springs of Queensland - Distribution and Assessment (Version 5.0)). This represents a relatively modest level of calibration and reflects the amount of data that is available for the site. The resultant groundwater model is still uncertain and it is anticipated that there will be inaccuracies in the predictive model outcomes described in this section. All model predictions should therefore be considered as estimates that include inherent inaccuracies. They do however illustrate the general physical processes and the types of impacts that are likely to arise from the dam construction and operation. The model is considered appropriate to assess the potential impact of the dam on groundwater.

Further description of the Nathan Dam groundwater model including model development, scenarios, assumptions and uncertainty are discussed in Appendix 15-E. Calibrated potentiometric surface maps for the Precipice and Hutton Sandstone aquifers are provided in Figure 15-20 and Figure 15-21 in Appendix 15-H.

15.2.3. Dam and surrounds

- Decreased groundwater levels associated with dewatering

Issue: Dewatering activities associated with the construction of the dam chimney filter will locally lower groundwater levels in the water table aquifer by up to 19 m.

Before installing the chimney filter, a dewatering program may be undertaken to drawdown the water table in the vicinity of the proposed dam foundation. It is anticipated that dewatering bores will be located around the excavation with some drilled into the Alluvium and others drilled deeper, into the underlying Precipice Sandstone. The bores will be pumped initially at a higher rate until dewatering has been achieved, reducing to a maintenance rate to keep the excavation dry. Dewatering is expected to occur over a period of approximately 50 days. Dewatering will result in groundwater drawdown, which in turn has the potential to reduce water availability to neighbouring groundwater users and GDEs.

The modelled drawdown associated with the dewatering activities is shown in Figure 15-8. Based on a search of the DERM groundwater database, there are no registered groundwater users that will be affected by the modelled drawdown. The closest known existing bore is located outside of the water storage and is approximately 2.7 km from the dam (RN 67281). The modelled impact on this groundwater user is negligible. As such, there will be no impact from the anticipated drawdown activities on existing groundwater users.

There are 20 registered springs that are likely to be impacted by drawdown activities, all of which are located downstream of the dam wall. Of these, four springs are likely to be impacted by a groundwater drawdown greater than 1 m in the vicinity of that spring (Figure 15-7). After dewatering activities are completed, it is anticipated that groundwater levels will recover quickly to pre-dewatering levels. The springs affected by the dewatering activities are presented in Table 15-9. There are no impacts anticipated for springs located upstream of the dam wall, or baseflow to streams.

Table 15-9 Model predicted groundwater drawdown at affected Boggomoss springs as a result of dewatering activities

Spring ID	Data source	Complex name	Modelled groundwater drawdown (m)
34	Springs of Queensland - Distribution and Assessment (Version 5.0)	DawsonRiver3	< 0.20
35			< 0.20
69			0.27
51		DawsonRiver4	1.1
50			1.6
47			0.87
49			0.80
46			0.73
45			0.58
48			0.66
B9	Chenoweth (2008)	New	0.27
B10		Possible #51	< 0.20
B11		New	< 0.20
B12		Possible #34	< 0.20
B13		Possible #34	< 0.20
B14		Possible #36	< 0.20
B8		New	1.9
B7		New	1.0
B16		Possible #69	< 0.20
B17		Possible #69	< 0.20

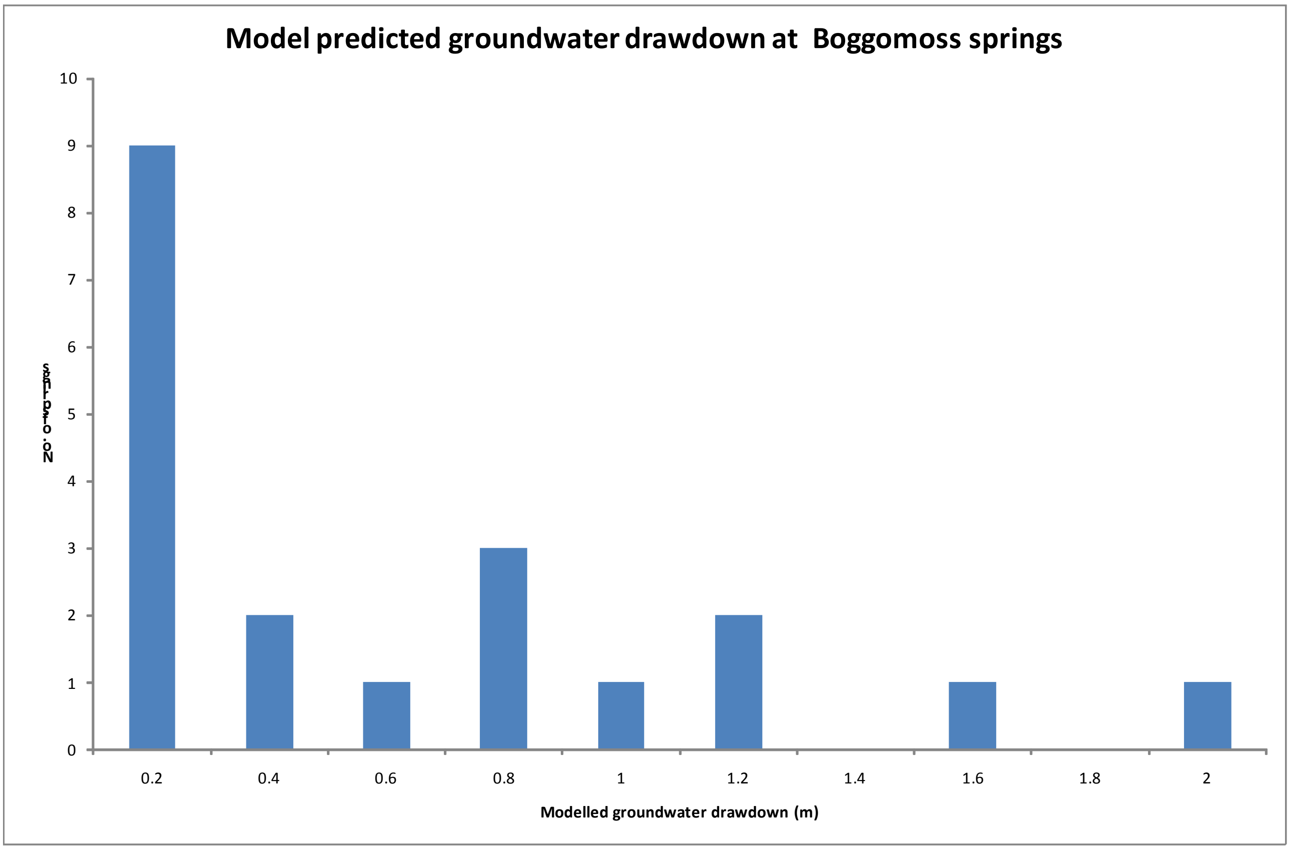


Figure 15-7 Histogram of model predicted groundwater drawdown at affected Boggomoss springs as a result of dewatering activities

Currently, there is a lack of knowledge relating to stygofaunal ecology within Australia (Tomlinson *et al*., 2007). As such, it is difficult to anticipate how the dewatering activities could potentially impact upon stygofauna communities within Project area.

Groundwater ecosystems are characterised by relatively stable environmental conditions compared with surface aquatic environments. The fact that fauna inhabiting groundwater environments are buffered from frequent fluctuations in environmental conditions taking place at the surface, could potentially mean that stygofauna are vulnerable to changes in groundwater regime. It is unknown however, how stygofauna respond to changes in water-level (Tomlinson and Boulton 2008; Tomlinson *et al*., 2007).

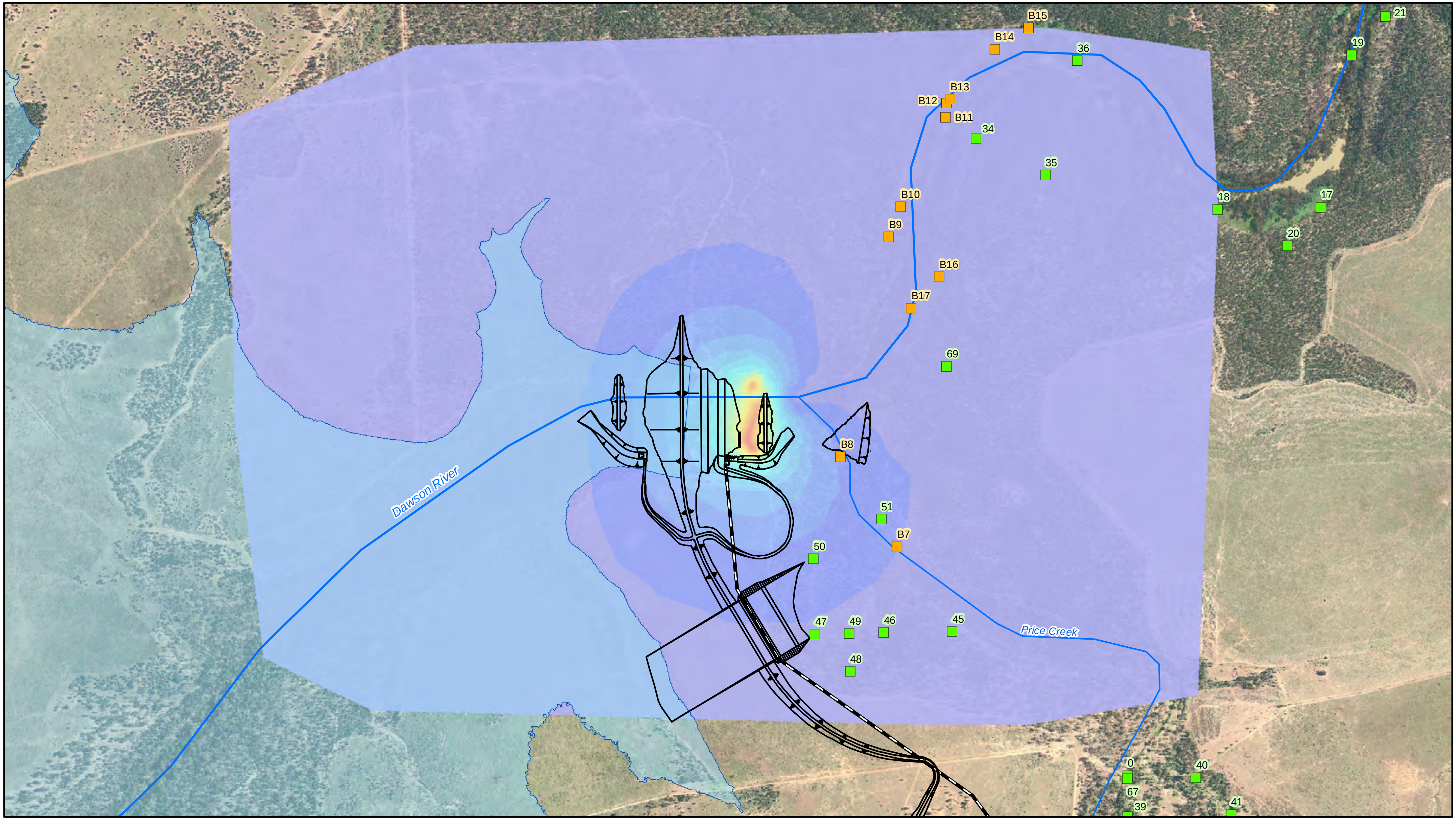
Studies have shown that when water table fluctuations occur at their natural rate, stygofauna are able to migrate vertically and maintain a position within the optimal physic-chemical environment. If, however, water is removed from an aquifer at too fast a rate, the stygofauna are likely to be unable to migrate (SKM, 2005). In previous experiments, stygofauna from the Hunter Valley in NSW have been observed to travel at approximately 20 cm/hr in an artificial environment (P. Hancock; pers. obs.). In natural environments however, where there is a higher degree of sediment packing, rates are thought to be likely as slow as 20 cm/day. In addition, dropping the water table too far below the natural range of fluctuation may transport stygofauna into deeper sections of the aquifer, or different sediment types, where environmental conditions are unfavourable (SKM, 2005).

Risk: Low - Extreme

Mitigation: The area of discharge and saturation, water quality and adjacent groundwater levels should be monitored at targeted springs. If a decrease in the discharge or saturation of Boggomoss springs is observed as a result of dewatering activities, irrigation of specific vegetation/spring region will be undertaken with dewatered groundwater. Further information on the monitoring at springs with respect to aquatic and terrestrial flora and fauna is provided in Sections 10 to 14.

Sampling for the presence of stygofauna communities should be undertaken from dewatering bores prior to the commencement of dewatering activities. Sampling should again be undertaken 3 and 6 months after the completion of dewatering to determine if re-colonisation of stygofauna communities has taken place. In addition, a reduced rate of groundwater extraction to allow for the slowest practical groundwater drawdown rate should be applied to allow for migration of stygofauna during dewatering activities.

A Groundwater Monitoring and Management Program will be established prior to dewatering activities to obtain baseline data and monitor groundwater levels and quality throughout the construction and dewatering phase. Groundwater monitoring is discussed further in Section 15.2.6.



LEGEND

- Proposed Pipeline
- Proposed Dam Arrangement
- Dawson River
- Watercourse
- Full Supply Level (183.5m AHD)

CEPLA GAB Spring Sites

- Outside FSL

Fensham GAB Spring Sites

- Outside FSL

Drawdown (m)

19 - 20
18 - 19
17 - 18
16 - 17
15 - 16
14 - 15
13 - 14
12 - 13
11 - 12
10 - 11
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1

Projection: GDA94 Zone 56

Figure 15-8

0 100 200 400
Metres

N

Scale 1:15,000 (at A4)

SKM SunWater Making Water Work

NATHAN DAM AND PIPELINES EIS

Modelled groundwater drawdown as a result of dewatering activities

- ### Disposal of dewatered groundwater

Issue: Disposal of groundwater as a result of dewatering may impact the receiving environment within the disposal areas.

Dewatering activities associated with the construction of the dam will be required for a period of ~ 50 days. Groundwater discharge from dewatering bores will be pumped to a sedimentation pond on the left bank of the river.

Risk: Medium

Mitigation: The water retained in sedimentation ponds is to be used to irrigate drying springs (if required), used on the construction site where possible, or progressively released back into the river under a water quality management plan.

- ### Decreased groundwater levels downstream of the dam as a result of dam wall construction and grouting

Issue: A reduction in downstream flow as a result of the dam wall has the potential to impact on the surface water-groundwater connectivity in areas downstream of the dam wall.

The Dawson River downstream of the dam wall is considered to be a gaining stream (i.e. groundwater discharge to the stream). A grout curtain has not been proposed for the dam construction (R. Paton; pers. comm.). Due to these two factors, it is anticipated a reduction in river flows downstream of the dam due to construction of the dam wall will have a negligible impact on groundwater levels.

Risk: Low

Mitigation: No mitigation activities

Monitoring of downstream groundwater levels will be undertaken to identify any impacts as a result of reduced downstream surface water flows. Groundwater monitoring is discussed in more detail in Section 15.2.6. An annual review of the collected data should be undertaken to identify any impacts and whether ongoing monitoring is required.

- ### Increased groundwater levels associated with dam inundation

*Issue: S*eepage loss and transfer of pressure from the weight of the dam water will result in an increase in the groundwater levels of the underlying aquifers.

The impact of dam inundation was modelled at full supply level (183.5 mAHD) and median supply level (181.7 mAHD) (Appendix 15-E). The impact of dam inundation is presented conceptually in Figure 15-9. The full supply level scenario can be considered a maximum impact scenario where the dam is maintained at full supply for an extended period.

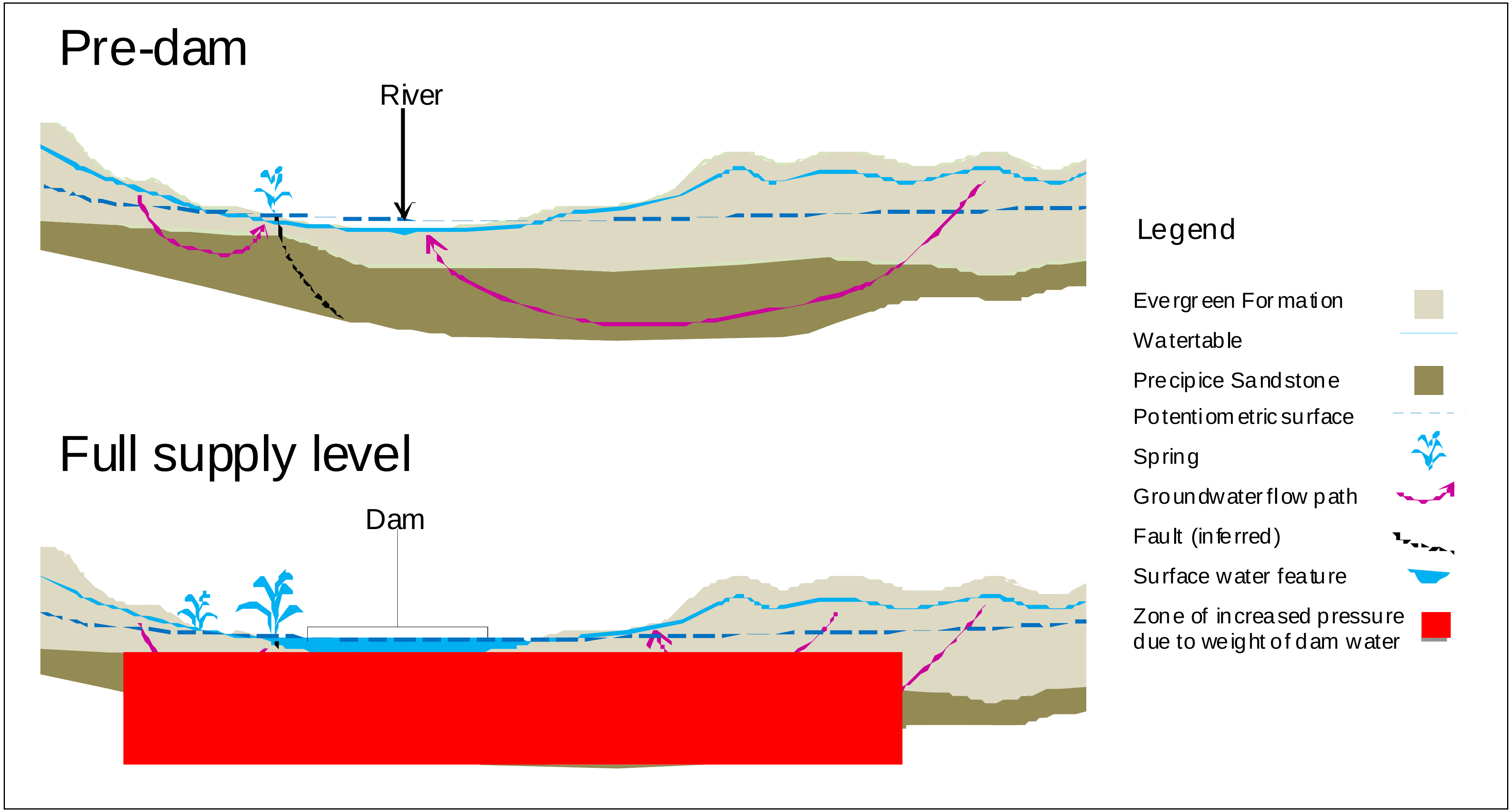


Figure 15-9 Schematic cross section showing the impact of dam inundation

The modelled increase in potentiometric surface associated with dam inundation and full and median supply levels is shown in Figure 15-H1 to Figure 15-H6 in Appendix 15-H. This increase in groundwater levels (up to a maximum of 183.5 m AHD) has the potential to increase baseflow to nearby streams and groundwater discharge to Boggomoss springs.

The modelled increase in groundwater discharge to the Dawson River downstream of the dam was 15% (~ 14 ML/day). This represents only a small proportion of the total flow in the river. Similar increases in baseflow are expected for other streams within the Project area. Current knowledge of spring flows from existing Boggomoss springs in the Project area are estimates, calculated from spring surface area. As such, it was not possible to model future discharges from Boggomoss springs with any certainty. The groundwater model does however allow for relative increases in spring flows.

Model predicted increases to flows from springs located downstream of the dam wall were 660%. Upstream of the dam wall, the model predicted increase to spring flows was 94% for the springs fed from the Precipice Sandstone and 851% for the springs located to the north of Taroom, fed from the Hutton Sandstone / Birkhead Formation. No increase in spring flows was observed for the spring located near Cockatoo Creek. The model predicted change in the groundwater levels at each spring as a result of dam inundation is tabulated in Appendix 15-F. The estimated time period for the model predicted increases in groundwater levels is within 10 years.

For the springs located to the north of Taroom, the magnitude of the model predicted increase to spring flows is difficult to conceptualise and is likely to be an anomaly in the groundwater modelling. These springs are located in close proximity to the full supply level inundation extent and could not be separated from this inundation within the groundwater model. As such, the increase to the groundwater levels of the underlying aquifers had a greater impact on these springs. In reality, the increase in flows from these springs is likely to be greater than 100%; however, the full magnitude of the increase cannot be determined with any certainty.

The increase in discharge from existing Boggomoss springs is likely to either manifest as an increase flow out of the current spring area, an increase to the overall spring area, or both. In addition, it is also likely that an increase in the potentiometric surface of the underlying aquifers will result in new spring sites. The location of these new sites is likely to be controlled by similar process as the current spring sites (i.e. fault controlled and thinning of the overlying aquitard). Hence, at full supply level new springs are likely to occur on the dark pink area shown on Figure 15-6 (where the Precipice Sandstone unit is artesian by more than 5 m and the overlying Evergreen Formation is less than 60 m thick).

Table 15-10 shows the Boggomoss springs that will be inundated at full supply level. An offset strategy will be required to ensure a no net loss outcome from inundated springs. Further information on the monitoring and mitigation measures at springs with respect to aquatic and terrestrial flora and fauna is provided in Chapters 10 to 14.

Table 15-10 Boggomoss springs inundated at full supply level

Spring ID	Data source	Complex name
25	Springs of Queensland - Distribution and Assessment (Version 5.0)	DawsonRiver6
31		DawsonRiver6
32		DawsonRiver6
12		Boggomoss
13		Boggomoss
30		DawsonRiver6
59		DawsonRiver6
54		Boggomoss
4		DawsonRiver6
14		Boggomoss
63		Boggomoss
29		Boggomoss
11		Boggomoss
3		Boggomoss
61		Boggomoss
53		Boggomoss
2		Boggomoss
33		Boggomoss
44		Boggomoss
37		Boggomoss
43		DawsonRiver6
42		DawsonRiver2
B4	Chenoweth (2008)	New
B3		New
B2		New
B1		New
B5		New
B6		New

Within the vicinity of the water storage, rises in the water table may bring salt to the surface where the piezometric surface approaches or reaches ground level. As the water evaporates, it leaves behind salt in the surface layers of the soil. This can lead to a gradual build up of salt within the soil causing salinisation if the water level fluctuates. As discussed in Chapter 6, the soils in the Project area are not saline in nature and the groundwater is typically fresh to slightly brackish. As such, this risk is assumed to be low.

Increased pressure in confined aquifers has the potential to result in catastrophic bore collapse, or bore casing failure for existing groundwater users. According to the DERM groundwater database, there are 157 registered groundwater users within the modelled area.

Existing groundwater bores should be ranked in terms of their risk of bore casing failure or catastrophic collapse according to the following factors:

- bore age (i.e. bores greater than 15 years old present a significantly greater risk);
- bore depth (i.e. deeper bores equal greater risk);
- casing material (i.e. bores cased in metals such as mild steel are at significantly greater risk than bores cased with inert materials, such as PVC or fibreglass);
- increase in groundwater head (i.e. increased pressure equals greater risk); and
- groundwater quality (salinity levels in excess of 1,200 to 1,500 mg/L TDS present a greater risk).

The change in the groundwater elevation at each groundwater bore as a result of dam inundation is tabulated in Appendix 15-G. There are seven registered groundwater users that will be inundated at full supply level. An offset strategy may need to be negotiated to ensure a no net loss outcome for these users. In addition, these bores will need to be decommissioned as per the *Minimum Construction Requirements for Water Bores in Australia (*Land and Water Biodiversity Committee, 2003).

It is difficult to anticipate how the above described changes in groundwater regime (water quantity/quality) could potentially impact upon stygofauna communities within Project area.

As stygofauna are restricted to subterranean aquifers, an increase in the groundwater level in the water table aquifer would be expected to increase the amount of available habitat within the aquifer. Unless accompanied by changes in water quality, elevation of the water table level would not be expected to negatively impact upon stygofauna communities.

Homogenisation of aquifer water table levels (i.e. reduction in naturally expected fluctuations in water table level) was listed by Hancock and Boulton (2008) as one of several reasons potentially explaining lower diversity in stygofauna communities observed in tributary aquifers. Although not mentioned in the context of a dam, this may suggest that regulation of the aquifer water table level expected following construction of the Nathan Dam could potentially result in decreased taxonomic diversity in stygofauna communities.

Risk: Medium - Extreme

Mitigation: Existing groundwater users should be ranked into categories of high, medium and low according to their risk of bore casing failure or catastrophic collapse. A program is required to assess, rehabilitate or replace bores identified as high risk of catastrophic collapse prior to dam operation. Ongoing bore monitoring of high risk bores should be monitored throughout dam operation. An offset strategy may also be required to ensure a no net loss outcome from inundated groundwater bores.

The area of discharge and saturation of springs, water quality and adjacent groundwater levels should be monitored. An offset strategy will be required to ensure a no net loss outcome from inundated springs and the expansion of flora and fauna in new discharge zones should also be monitored and land management practices reviewed to ensure protection of these areas. Further information on the monitoring and mitigation measures at springs with respect to aquatic and terrestrial flora and fauna is provided in Sections 10 to 14.

Sampling for the presence of stygofauna communities should be undertaken prior to dam inundation. Sampling should again be undertaken yearly throughout dam operation to reconfirm presence of stygofauna communities.

A Groundwater Monitoring and Management Program will be established prior to dam construction to obtain baseline data and monitor groundwater levels throughout operation to observe the impact of dam inundation. This groundwater monitoring and management program is discussed in more detail in Section 15.2.6.

Changes in groundwater salinity

Issue: Seepage loss from the dam has the potential to impact on the groundwater quality of the underlying aquifer and hence impact on groundwater users and GDEs.

In the vicinity of the dam, groundwater in the underlying aquifer is typically fresh to slightly brackish. Surface waters stored within the dam will likely be of potable quality (i.e. better quality than groundwater) and as such will be at least of a comparable or better raw water quality to surrounding groundwater. In areas where groundwater quality is slightly brackish, there may be a freshening of groundwater quality as a result of the seepage from low salinity dam water. The impact of this seepage of surface water into the groundwater will be most significant in the vicinity of the water storage, however away from the inundation, the fresher water will equilibrate with the surrounding groundwater and the impact will become negligible.

The relationship between stygofauna and water quality is poorly understood (Tomlinson and Boulton 2008). Although stygofaunal community composition and/or species distribution has been weakly correlated to individual water quality parameters such as electrical conductivity, pH, dissolved oxygen, water temperature and nutrient concentrations (dissolved organic carbon, nitrogen and phosphorus) patterns are not consistent and conflicting results exist (Tomlinson and Boulton 2008). Accordingly, it is difficult to anticipate how changes in specific water quality parameters within the aquifer, following construction of the dam, could potentially impact upon stygofauna communities.

Stygofauna communities inhabiting the Burnett and Pioneer aquifer's were observed to be tolerant to pH values ranging from 4.33 to 6.53, electrical conductivity concentrations ranging from 204 to 18980 uS/cm, water temperature ranging from 16.6 to 26.6 °C and dissolved oxygen concentrations ranging from 0.23 to 5.03mg/L (Hancock and Boulton 2008). The fact stygofauna communities were observed to persist in such a wide range of water quality conditions, suggests that the slight change in water quality expected following construction of the dam, will not significantly impact upon stygofauna communities that may be present. That said, available data indicates that most stygofauna taxa exhibit a high degree of endemism; often confined to a single aquifer (Humphreys 2008). As such, caution should be exercised when comparing stygofauna communities inhabiting different aquifers, as each community is likely to be composed of endemic species – with each species potentially exhibiting different tolerance ranges to various physio-chemical parameters.

Risk: Medium

Mitigation: No mitigation activities

A Groundwater Monitoring and Management Program will be established prior to dam construction to obtain baseline data and monitor groundwater quality throughout operation to observe the impact of dam inundation. A groundwater monitoring and management program is discussed in more detail in Section 15.2.6.

- Contamination of groundwater

Issue: Improper storage and use of chemicals, fuels and waste products during construction and operation phases of the Project have the potential to locally impact upon groundwater quality, which in turn may impact neighbouring groundwater users and GDEs.

Provided these activities are undertaken in an appropriate manner and with respect to the relevant guidelines, the potential for groundwater contamination is considered negligible.

Risk: Low

Mitigation: The above activities will be undertaken within the framework of an Environmental Management Plan. In the event that contamination on-site has occurred, a site specific environmental investigation will be undertaken. Site specific remediation options will be developed based on findings from the environmental investigation.

15.2.4. Pipeline

The proposed pipeline is described in Chapter 2.

- Groundwater dewatering

Issue: Pipeline construction activities associated with creek crossings may require dewatering where groundwater is intersected. This has the potential to locally impact on surface water - groundwater interaction for a short period.

For watercourses along the pipeline that flow intermittently or are ephemeral, works are programmed for the dry season. Hence, it is expected that these watercourses will be dry when crossed. For watercourses that contain water the trench area will be isolated by coffer dams constructed from excavated material from either the pipeline trench or imported material. It may also be necessary to dewater the trench using pumps and discharge the water downstream. In most stream beds the pipeline will be encased in concrete. It is not essential that the trench be fully dewatered however in order to place the concrete.

Risk: Medium

Mitigation: The depths of groundwater at creek crossings will be confirmed as part of geotechnical investigations and results will be assessed to determine whether dewatering will be required. Any water dewatered during trench excavation will be returned to the creek to facilitate the return to the groundwater system. Any required dewatering activities will be temporary (i.e. during construction phase) and it is anticipated that groundwater levels will recover following the conclusion of groundwater extraction or dewatering.

- Groundwater contamination

Issue: Improper storage and use of chemicals, fuels and waste products during construction and operational phases of the Project have the potential to locally impact upon groundwater quality.

These activities will be managed through a project specific Environmental Management Plan as noted above.

Risk: Low

Mitigation: As above for the dam.

- Rising groundwater levels from pipeline rupture

Issue: A rupture in the pipeline may cause a temporary and localised rise in groundwater levels in the water table aquifer

Risk: Low

Mitigation: Regular maintenance and monitoring of the pipeline will reduce the likelihood of pipeline rupture. In the event pipeline rupture occurs, sufficient shut down or cut-off mechanisms will be put in place to prevent continued spillage of water

- Changes in groundwater quality from pipeline rupture

Issue: A rupture in the pipeline may infiltrate into the underlying aquifer and impact on groundwater quality

The quality of water being transferred via the pipeline will be raw water from the water storage. In the event that pipe integrity is compromised and leakage occurs, water from the pipe will be at least of a comparable water quality to surrounding fresh groundwater. In areas where groundwater quality is slightly brackish, there may be a freshening of groundwater quality as a result of any infiltration from low salinity dam water.

Risk: Low

Mitigation: Regular maintenance and monitoring of the pipeline will reduce the likelihood of pipeline rupture. In the event pipeline rupture occurs, sufficient shut down or cut-off mechanisms will be put in place to prevent continued spillage of water

15.2.5. Impact assessment and residual risks

- Cumulative risks

No cumulative impacts are expected as a result of dam construction or operation, with respect to the groundwater system.

With the exception of the dewatering activities, which have very localised impacts and are short in duration (~ 50 days), the main impact associated with dam construction and operation relates to increased groundwater levels associated with dam inundation. That is, seepage loss and transfer of pressure from the weight of the dam water will result in an increase in the groundwater levels of the underlying aquifers. It is anticipated that this impact will act to offset or counter balance to some degree the impacts of the other projects in the region that are extracting groundwater from the same aquifer system (i.e. groundwater users, CSG industry).

Unmitigated consequence and likelihood ratings for each of the identified hazards and the assessment of residual risks after mitigation are summarised in Table 15-11. .

Table 15-11 Risk register

Groundwater Dam

Hazards	Factors	Impacts	Project Description Controls & Standard Industry Practice	Risk with Controls			Additional Mitigation Measures	Mitigation Effectiveness	Residual Risk		
				C	L	Current Risk			C	L	Mitigated Risk
Decreased groundwater levels associated with dewatering.	Dewatering activities associated with the construction of the dam chimney filter will locally lower groundwater levels up to 19 m for the period of dewatering (~ 50 days). It is anticipated that groundwater levels will quickly recover following completion of dewatering activities	Potential for reduced groundwater discharge to 20 Boggomoss springs located downstream of the dam wall.	Reduced rate of groundwater extraction to allow for the slowest practical groundwater drawdown rate	Major	Almost certain	Extreme	If a decrease in the discharge or saturation of Boggomoss springs is observed as a result of dewatering activities, irrigation of specific vegetation/spring region will be undertaken using dewatered groundwater	Significantly	Moderate	Almost certain	High
		No impacts anticipated for springs located upstream of the dam wall, baseflow to streams or existing groundwater users.		Minor	Unlikely	Low	No mitigation activities	None	Minor	Unlikely	Low
		Potential for decreased taxa diversity in stygofauna communities		Moderate	Likely	High	No mitigation activities	None	Moderate	Likely	High

Groundwater Dam

Hazards	Factors	Impacts	Project Description Controls & Standard Industry Practice	Risk with Controls			Additional Mitigation Measures	Mitigation Effectiveness	Residual Risk		
				C	L	Current Risk			C	L	Mitigated Risk
Disposal of dewatered groundwater.	Dewatering activities associated with the construction of the dam will be required for a period of ~ 50 days	Disposal of groundwater as a result of dewatering may impact receiving environment within the disposal areas.	Groundwater discharge from dewatering bores will be pumped to a sedimentation pond on the left bank of the river	Minor	Possible	Medium	The water retained in sedimentation ponds is to be used to irrigate drying springs (if required), used on the construction site where possible, or progressively released back into the river under a water quality management plan.	Significantly	Minor	Unlikely	Low
Decreased groundwater levels downstream of the dam as a result of dam wall construction and grouting.	The Dawson River downstream of the dam wall is considered to be a gaining stream (i.e. groundwater discharge to the stream). A grout curtain has not been proposed for the Dam construction.	A reduction in river flows downstream of the dam due to construction of the dam wall is unlikely to impact on groundwater levels downstream of the dam.	No operational controls	Minor	Unlikely	Low	No mitigation activities	None	Minor	Unlikely	Low

Groundwater Dam

Hazards	Factors	Impacts	Project Description Controls & Standard Industry Practice	Risk with Controls C	Risk with Controls L	Risk with Controls Current Risk	Additional Mitigation Measures	Mitigation Effectiveness	Residual Risk C	Residual Risk L	Residual Risk Mitigated Risk
Increased groundwater levels associated with dam inundation.	Seepage loss and transfer of pressure from the weight of the dam water will result in an increase in the groundwater levels of the underlying aquifers	Potential increase of groundwater discharge to springs located downstream of the dam wall by 660%	No operational controls	Major	Almost certain	Extreme	Review of land management practices to ensure protection of flora and fauna in new discharge zones.	Significantly	Moderate	Almost certain	High
		Potential increase of groundwater discharge to springs located upstream of the dam wall by 94%, for springs fed from the Precipice Sandstone, and > 100% for springs fed from the Hutton Sandstone		Major	Almost certain	Extreme	As above	Significantly	Moderate	Almost certain	High
		Potential increase of baseflow to the Dawson River and associated streams by 15%		Minor	Almost certain	Medium	No mitigation activities	None	Minor	Almost certain	Medium
		Increased pressure in confined aquifers has the potential to result in catastrophic bore collapse, or bore casing failure for existing groundwater users		Major	Likely	High	Assess, rehabilitate or replace bores identified as high risk of catastrophic collapse prior to dam operation.	Significantly	Minor	Possible	Medium

Groundwater Dam

Hazards	Factors	Impacts	Project Description Controls & Standard Industry Practice	Risk with Controls			Additional Mitigation Measures	Mitigation Effectiveness	Residual Risk		
				C	L	Current Risk			C	L	Mitigated Risk
		Potential for decreased taxa diversity in stygofauna communities		Moderate	Likely	High	No mitigation activities	None	Moderate	Likely	High
Changes in groundwater salinity.	Seepage loss from the dam has the potential to impact on the groundwater quality of the underlying aquifer.	Potential impacts on groundwater users and GDEs. The impact of this seepage of surface water into the groundwater will be most significant in the vicinity of the dam water storages, however away from the inundation, the fresher water will equilibrate with the surrounding groundwater and the impact will become negligible.	No operational controls	Minor	Likely	Medium	No mitigation activities	None	Minor	Likely	Medium

Groundwater Dam

Hazards	Factors	Impacts	Project Description Controls & Standard Industry Practice	Risk with Controls			Additional Mitigation Measures	Mitigation Effectiveness	Residual Risk		
				C	L	Current Risk			C	L	Mitigated Risk
Groundwater contamination.	Improper storage and use of chemicals, fuels and waste products during construction and operational phases of the Project have the potential to locally impact upon groundwater quality.	Potential impacts to neighbouring groundwater users, streams, Boggomoss springs and associated GDEs.	These activities will be managed through a project specific Environmental Management Plan.	Minor	Unlikely	Low	In the event that an unplanned spill or incident occurs within the construction area or as part of associated activities of the Project, targeted groundwater quality monitoring will be carried out to determine potential impacts from the contamination. Site specific remediation options will be developed based on findings from the environmental investigation.	Significantly	Insignificant	Unlikely	Low

Groundwater Pipeline

Hazards	Factors	Impacts	Project Description Controls & Standard Industry Practice	Risk with Controls			Additional Mitigation Measures	Mitigation Effectiveness	Residual Risk		
				C	L	Current Risk			C	L	Mitigated Risk
Groundwater Dewatering	Pipeline construction activities associated with creek crossings may require dewatering where groundwater is intersected.	Potential localised impacts to surface water - groundwater interaction	No operational controls	Minor	Likely	Medium	Construction work at creek crossing will be undertaken during the dry season. Any groundwater intersected during construction works at creek crossings and trench excavation will be returned to the creek to facilitate the return to the groundwater system	Significantly	Insignificant	Unlikely	Low
Groundwater contamination	Improper storage and use of chemicals, fuels and waste products during construction and operational phases of the Project have the potential to locally impact upon groundwater quality.	Potential impacts to neighbouring groundwater users, streams and GDEs.	As above for the dam.	Minor	Unlikely	Low	As above for the dam.	Significantly	Insignificant	Unlikely	Low

Groundwater Pipeline

Hazards	Factors	Impacts	Project Description Controls & Standard Industry Practice	Risk with Controls			Additional Mitigation Measures	Mitigation Effectiveness	Residual Risk		
				C	L	Current Risk			C	L	Mitigated Risk
Rising groundwater levels from pipeline rupture	A rupture in the distribution pipeline may cause a temporary and localised rise in groundwater levels in the water table aquifer	Localised impacts to flow patterns	Regular maintenance and monitoring of the pipeline to reduce the likelihood of pipeline rupture.	Minor	Unlikely	Low	In the event pipeline rupture occurs, sufficient shut down or cut-off mechanisms will be put in place to prevent continued spillage of water	Significantly	Insignificant	Unlikely	Low
Changes in groundwater quality from pipeline rupture	A rupture in the pipeline may infiltrate into the underlying aquifer and impact on groundwater quality	The quality of water being transferred from the dam via the pipeline should be of potable quality (i.e. higher quality than groundwater). As such, the impacts to neighbouring groundwater users, streams, Boggomoss springs and associated GDEs will be minor	Regular maintenance and monitoring of the pipeline to reduce the likelihood of pipeline rupture.	Minor	Unlikely	Low	In the event pipeline rupture occurs, sufficient shut down or cut-off mechanisms will be put in place to prevent continued spillage of water	Significantly	Insignificant	Unlikely	Low

15.2.6. Groundwater monitoring

A Groundwater Monitoring and Management Program will be developed and implemented prior to dam construction to establish baseline groundwater data. This baseline groundwater data will serve as guideline levels to enable identification of any impacts during the construction and operation phases of the Project. Groundwater monitoring should be undertaken on a monthly basis for six to twelve months prior to commencement of construction phase, monthly during construction (weekly during dewatering activities) and quarterly during operations. A review of the any existing groundwater monitoring bores will be undertaken to determine whether these bores are sufficient to capture the data required. Annual reviews of the collected data should be undertaken to identify any impacts and whether ongoing monitoring is required.

15.2.6.1. Dewatering

A Groundwater Monitoring and Management Program during the construction phase of the Project should include, but not be limited to the following:

- a series of monitoring bores at the edge of the expected cone of depression to monitor the extent of the drawdown. Additional monitoring bores located beyond the expected drawdown cone will act as controls to ensure the drawdown does not exceed beyond the expected range and hence increase the area of impact. Parameters to be tested should include groundwater levels (referenced to m AHD and m BGL), EC and pH;
- soil moisture monitoring at the periphery of targeted springs. This will assist in measuring the area of discharge and saturation and act as a trigger for potential irrigation of specific vegetation / spring region; and
- a transect of shallow bores located at targeted springs to assist in understanding the controls on the springs and hence the impact of drawdown on the area of discharge and saturation.

15.2.6.2. Operation

A Groundwater Monitoring and Management Program during the operation phase of the Project should include, but not be limited to the following:

- a series of nested monitoring bores (bores at different depth at the same location) at targeted elevations and locations to monitor the increase in the potentiometric surface and changes in groundwater quality. Groundwater levels monitored should be referenced to both m AHD and m BGL. Automated groundwater level data recorders are suggested. Groundwater quality monitoring should include analysis of EC and pH;
- soil moisture monitoring at the periphery of targeted springs. This will assist in measuring the expansion rates in the area of discharge and saturation; and
- a transect of shallow bores located at targeted springs to assist in understanding the controls on the springs and hence identify increases to the rate of discharge or the area of discharge.

Stream gauge analysis at the Nathan Gorge gauge (GS 130320A) should be undertaken to identify the change in baseflow.

A Bore Monitoring and Management Program should be developed and implemented prior to dam construction. The monitoring program should include, but not be limited to the following:

- ranking of existing groundwater users in terms of their risk of bore casing failure or catastrophic collapse;
- CCTV of high risk bores to detect areas of heavy corrosion and hence potential for failure;
- review of class strength or collapse strength of medium risk bores;
- appropriate ongoing monitoring of high value irrigation bores including assessment of physical characteristics to alert to potential for bore failure; and
- decommissioning of bores that will be inundated as per the *Minimum Construction Requirements for Water Bores in Australia (*Land and Water Biodiversity Committee, 2003).

15.2.7. Groundwater extraction bores and decommissioning of temporary groundwater bores

Drilling and construction of groundwater extraction bores will be undertaken in accordance with *Minimum Construction Requirements for Water Bores in Australia (*Land and Water Biodiversity Committee, 2003). Bores installed to a depth greater than 6 m BGL will be registered with DERM in accordance with the *Water Act 2000* and will require a licensed driller to undertake the works. A water permit or water licence will be required to extract groundwater in accordance with the requirements of DERM.

Following the conclusion of dewatering and monitoring operations, bores may be required to be decommissioned. As part of this process, to seal and abandon a groundwater bore properly, several requirements must be met. These include:

- elimination of any physical hazard;
- prevention of groundwater contamination;
- conservation of yield and maintenance of hydrostatic head of aquifers; and
- prevention of the intermingling of desirable and undesirable waters.

The minimum requirements for decommissioning bores as outlined in *Minimum Construction Requirements for Water Bores in Australia (*Land and Water Biodiversity Committee, 2003) will be adhered to.

15.3. Summary

Assessment of the existing hydrogeological environment is summarised below:

- there are three main aquifers systems that will potentially be impacted by the dam. These are:
  - Precipice Sandstone and Hutton Sandstone- significant consolidated sandstone aquifers of the Surat Basin; and
  - minor to significant unconsolidated sedimentary aquifers associated with the alluvium of the Dawson River and its major tributaries;
- regional groundwater flow patterns indicate that recharge to the Precipice and Hutton Sandstones occurs in the outcrop areas located well to the west and north of the dam site and that groundwater flows largely to the south-east

before discharging along the Dawson River and Boggomoss springs. There is also localised recharge occurring via infiltration of rainfall on exposed outcrops of Precipice Sandstone on the flanks of the Dawson River valley;

- recharge to the alluvium of the Dawson River occurs via a combination of mechanisms including, direct infiltration of rainfall; infiltration of stream flow, particularly during flood periods; and upward leakage of artesian water from underlying formations. Groundwater discharge from the Alluvial aquifer occurs primarily as down-valley through flow or discharge into streams;
- there are 83 registered springs within the Project area. All are associated with discharge from the Precipice Sandstone, except for a series of springs located in the Palm Creek area. These springs were believed to be associated with groundwater discharge from the Hutton Sandstone / Eurombah Formation;
- the Dawson River is fed by springs that contributes to its permanent flow;
- the use of groundwater for on-site purposes (such as dust suppression, etc.) has not been identified as a requirement for pre-construction, construction, and operational phases of the Dam;
- dewatering activities associated with the construction of the dam chimney filter will locally lower groundwater levels in the water table aquifer by up to 19 m; and
- seepage loss and transfer of pressure from the weight of the dam water will result in an increase in the groundwater levels of the underlying aquifers.

Potential impacts to groundwater system arising from the construction and operation of the dam were identified using available knowledge of groundwater occurrence in the Project area and development of a groundwater model. It is considered that identified groundwater impacts arising from the Project can be addressed through implementation of appropriate management activities and monitoring. It is not anticipated that any significant risks relevant to groundwater resources will remain after mitigation.

Groundwater monitoring will be required to be undertaken to monitor potential impacts and confirm predictions.